

**Neurophysiological evidence for the influence of phonological
and semantic neighbourhood densities on word production
in children and adults**

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by

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Abstract

This thesis aimed to explore the effects of phonological and semantic neighbourhood densities during word production in children. Neighbourhood density refers to the number of words that are related to each other, and its influence on language production has been examined in numerous behavioural studies. By making use of electroencephalography (EEG) and event-related potentials (ERPs) the present experiments approached the effects of phonological and semantic neighbourhood densities from a new angle. The use of ERPs allows the identification of underlying processing differences, revealing thereby associated processing demands.

Different children's groups named pictures varying in phonological and semantic neighbourhood densities while EEG data were collected. The novel findings identify changes of underlying processing costs depending on a word's neighbourhood density and provide new insights into the impact of word-inherent properties on information retrieval during speech production.

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Introduction and overview

The seemingly effortless production of a single word requires the involvement of various cognitive processes, including the retrieval of the word meaning (semantics) and its sound properties (phonological form), before it can be audibly articulated. The ease of retrieval can therefore be influenced by various factors such as the speaker's language proficiency, but also by characteristics inherent in the intended word itself. One of these characteristics is how a word is related or interconnected to other words (deemed neighbours) in an individual's mental lexicon (a component of the long-term memory that stores information regarding a word's meaning, form and pronunciation). The number of neighbours reflects the strength of interconnectedness of words (neighbourhood density) and has been found to affect word processing. Relatedness among words can refer to phonological or semantic aspects. Both factors, that is, phonological and semantic neighbours, are considered in this dissertation.

The impact of phonological neighbours on speech production has been demonstrated in past behavioural research (e.g., Vitevitch & Stamer, 2006; Vitevitch, 2002). Depending on the number of phonological neighbours, word production speed and accuracy varies, underpinning a different processing demand. But findings are inconsistent and do not allow for a clear statement regarding the relative effect of phonologically

dense words and phonologically sparse words, that is, whether the former or the latter are more demanding.

The seemingly effortless acquisition of language is a precondition for successful social communication and educational achievement. However, recent findings from language acquisition research suggest that phonological neighbourhood density is implicated in vocabulary development in young children (Stokes, 2014). Findings show that toddlers who struggle to talk mainly produce words that have many phonological neighbours while their typically developing peers use words that have either many or few phonological neighbours. These findings indicate a differential processing demand depending on a word's phonological neighbourhood density. For this reason, phonological neighbourhood density is an important topic to investigate from a clinical perspective, yielding a better understanding of linguistic factors identified as potential predictors of language development and word retrieval. The studies presented in this dissertation aim to contribute to a better understanding of the impact of phonological neighbourhood density during speech production in children, in order to support the development of adequate interventions in therapeutic contexts.

To date, discrepant reports on the effects of phonologically dense and phonologically sparse words make it difficult to infer associated processing demands during language production. The thesis addresses this issue:

1. The main goal is to provide more insights into the effects of phonological neighbourhood density during word production in children, and to reveal whether the processing of phonologically dense words or phonologically sparse words is more demanding. As previous behaviourally based measures do not provide clarity, new ways of measuring are needed to provide a better understanding of the associated ease of processing.

2. In the process of answering the first question regarding the impact of phonological neighbours on word production, the second question arose: How do semantic neighbours affect word retrieval during speech processing in children?

Past research points to the influence of semantically related words on language production but focussed mostly on the manipulation of semantic contexts, rather than on word-inherent semantic properties (e.g., Abdel Rahman & Melinger, 2007; Costa, Alario, & Caramazza, 2005). Less is known about the impact of semantic neighbours on word processing. Revealing the effects of semantic neighbourhood density on word production provides a better understanding of how semantic neighbours contribute to word retrieval, which can be relevant for clinical practice.

Behavioural approaches have provided ground-breaking evidence by revealing word-production differences that depend on the phonological or semantic interconnectedness of words. However, behavioural measurements are limited by their inability to reveal underlying

processing demands during word production, which is required to better understand causes of word retrieval failure or delay.

Electrophysiological methods like electroencephalography (EEG) and event-related potentials (ERP) have been successfully used to explore underlying processing differences during language production. Several advantages of EEG/ERP make it an attractive method for studying the effects of neighbourhood density during speech production. EEG/ERP tracks the time course of processing activity in milliseconds and allows the discovery of underlying processing differences in terms of neighbourhood densities. Recent research has also explored the chronometry of the underlying processes involved in word production during picture naming (Indefrey & Levelt, 2004; Indefrey, 2011; Laganaro, Tzieropoulos, Frauenfelder, & Zesiger, 2015), which allows the mapping of processing differences to particular mental operations. In addition, EEG is a noninvasive method, which makes it further applicable to children. EEG has been used with infants as young as eight months old in language development research (e.g., Pannekamp, Weber, & Friederici, 2006).

This dissertation has used EEG/ERP methods to complement behavioural data and to reveal the different processing demands associated with the production of words varying in phonological and semantic neighbourhood densities. The thesis is structured as follows:

The first chapter outlines the potential impact of phonological neighbourhood density on word production in developing and mature language systems. The reviewed findings illustrate the need for further

investigations that provide more insights into the effect of phonological neighbourhood density on word production.

The second chapter details the picture-naming process and its temporal sequence, thereby providing the foundation that allows the exposure of the effect of phonological neighbourhood density during speech production.

Chapter 3 describes the methodology used in the experimental part of this dissertation, including a review of the contribution of EEG in previous studies investigating the impact of linguistic variables on word production.

Chapter 4 discusses two pilot experiments that make a first attempt to explore the effect of phonological neighbourhood density during the process of word production in healthy speakers. Taking advantage of the technique of EEG/ERP this new approach required the inclusion of adults before targeting younger people. As findings from adults yielded the expected outcomes, proof of concept with children was subsequently demonstrated. The results from the pilot experiments raised the question of the influence of semantic neighbours on word retrieval, and led to the experimental paradigm used for the EEG experiments presented in Chapter 6.

Chapter 5 outlines the potential impact of semantically related words on word production, and illustrates the issue of defining semantic neighbourhood density before providing a definition used in this thesis.

Chapter 6 will present two EEG/ERP experiments on how phonological and semantic neighbourhood densities affect underlying processes of word production in children.

The final chapter is a conclusion of the dissertation studies, including the contributions, implications and future directions.

Chapter 1

The effect of phonological neighbourhood density on word production

1.1 Phonological neighbourhood density

The number of words in the mental lexicon that are phonologically connected to a given word is referred to as a word's phonological neighbourhood density (PND). The most common metric to quantify this density is produced by calculating the number of words in the language that differ from any given target word by a single phoneme substitution, deletion, or addition (Ph+/-1; Luce & Pisoni, 1998). For example, among the phonological neighbours of the word *cat* (/kæt/) would be *rat* (/ræt/), *cap* (/kæp/), *cut* (/kʌt/), *at* (/æt/) and *scat* (/skæt/). Since the number of neighbours can vary across words, it is said that a word with many phonological neighbours has a high PND and resides in a dense neighbourhood (e.g., *cat* has 35 phonological neighbours), whereas a word with only a few neighbours has a low PND and resides in a sparse neighbourhood (e.g., *frog* has 6 phonological neighbours). Importantly, these phonological parameters have been identified as affecting word retrieval during speech production in mature as well as in developing language systems, as PND is implicated in vocabulary development.

1.2 Predictors of vocabulary development

In recent years researchers in the field of language development have identified the significance of statistical properties of the ambient language in emerging lexicons (Stokes, Bleses, Basbøll, & Lambertsen, 2012; Stokes, Kern, & dos Santos, 2012; Stokes, 2010; Storkel, 2004, 2009). Storkel (2004) conducted an analysis, based on parental report data, of the expressive (spoken) vocabularies in typical toddlers in the age range from 0;8 (year;month) to 2;6. Storkel found that early acquired words tend to have many phonological neighbours, are shorter in length and occur more frequently in the ambient language than late acquired words. Based on these findings, Stokes and colleagues (Stokes, Bleses, et al., 2012; Stokes, Kern, et al., 2012; Stokes, 2010) investigated the impact of PND, word length and word frequency with respect to the vocabulary size of the expressive lexicon in toddlers aged 2;0 to 2;6. Using also parental report data, results from regression analysis revealed that PND accounted for the largest proportion of the variance in vocabulary size, thereby showing the strongest impact on word learning. Importantly, they found that children with small expressive vocabularies (one standard deviation below the mean for age) used predominantly words that had many phonological neighbours in the ambient language. In comparison, children with average to large vocabularies had significantly lower average PND values than children with small vocabularies.

Children who show a slow onset of expressive vocabulary at the age of 2 years are described as late talkers (LTs; Ellis Weismer, 2007;

Rescorla, 1991). Most children produce approximately 300 words by this age (Fenson et al., 1994), whereas LTs say fewer than 50 words. The novel findings reported by Stokes and colleagues (Stokes, Bleses, et al., 2012; Stokes, Kern, et al., 2012; Stokes, 2010), however, emphasises also a qualitative difference besides the quantitative dissimilarity in vocabulary development, and gives rise to the question about the role of PND for LT children. Stokes (2014) started to address this question by examining not only the expressive, but also the receptive vocabulary (understood but not said) in 13 LTs and 50 typically developing (TD) children at two time points: at the age of 1;6 and 2;0 years. At the age of 1;6 years both groups had similar-sized combined lexicons (understood and spoken). But the spoken lexicons of LTs were significantly smaller than those of the TD children. By the age of 2;0 years, LTs had significantly smaller combined lexicons compared to their TD peers. While the latter children increased their spoken vocabulary significantly, the difference in expressive vocabulary size at 1;6 and 2;0 for LT children was minimal (Stokes, 2014).

Turning to the qualitative difference between the two groups, or rather the difference in word types, results revealed that at both time points the receptive vocabularies of LT and TD children did not differ in the mean PND values, that is, they were equally composed of sparse and dense words. But compared with their TD peers, the mean PND values were significantly higher in the expressive lexicons of LTs, that is, they produced mainly words from denser neighbourhoods. Putting these

findings in another way, while the TD peers began to add words from sparse portions of the ambient language to their expressive lexicon between 1;6 and 2;0, LTs did not. Although LT children understand phonologically sparse words, their production is limited to words from denser neighbourhoods. The fact that the word meaning is available in their lexicon points to deficits regarding the word form. Stokes (2014) proposed that phonologically sparse words remain in the receptive lexicon “because phonological representations for sparse words are not robust enough to facilitate word retrieval for production” (p. 20). Unlike low PND words, high PND words are composed of phonological strings that are repeated across many words, which may generate strong phonological representations, making dense words more easily accessible in word production (Stokes, 2014). These findings therefore suggest that the production of sparse words places a different demand on the underlying processes of speech production compared to dense words, thereby affecting expressive vocabulary development; this relationship suggests that PND is a potential predictor of language development. Based on these results, researchers need to investigate the effects of PND more closely to gain a better understanding about its potential impact during word production.

Supportive evidence for the influential role of PND on word retrieval during speech production comes from behavioural studies in children and adults, which will be examined in more detail in the following section.

1.3 The effects of phonological neighbours

Empirical behavioural studies have repeatedly reported the influence of PND on speech production in adults and children, since PND affects naming latency (Arnold, Conture, & Ohde, 2005; Baus, Costa, & Carreiras, 2008; Sadat, Martin, Costa, & Alario, 2014; Vitevitch & Stamer, 2006; Vitevitch, 2002), naming accuracy (Bernstein Ratner, Newman, & Streckas, 2009; Freedman, 2013; Stemberger, 2004; Vitevitch, 2002) and word finding (German & Newman, 2004; Newman & German, 2002; Vitevitch & Sommers, 2003) in healthy as well as in clinical individuals (Arnold et al., 2005; Bernstein Ratner et al., 2009; Laganaro, Chetelat-Mabillard, & Frauenfelder, 2013; Middleton & Schwartz, 2011).

While researchers agree that PND affects information retrieval during language production, behavioural findings regarding the direction of PND effects are less consistent. For example, investigating the naming performance in English-speaking adults during a picture-naming task, Vitevitch (2002) reported faster response times for words with high PND compared to words with low PND (for similar findings in Spanish-speakers see Baus et al., 2008), indicating a facilitative effect of phonologically dense words. However, in a later study with Spanish-speaking adults Vitevitch and Stamer (2006) found faster naming latencies for words from sparse neighbourhoods than from dense neighbourhoods, a finding that was replicated by Sadat et al. (2014). These outcomes point to an inhibitory effect of dense words. Ambiguous results were also reported in studies using the picture-naming task in children. Arnold et al. (2005)

observed slower production latencies for targets with high PND compared with low PND in 3- to 5-year-old children, whereas Bernstein Ratner et al. (2009) found no effect of PND on response latencies in children aged 5 to 16 years. Yet, Bernstein Ratner et al. (2009) observed an effect on naming accuracy. Children erred on words from sparse neighbourhoods significantly more than on words from dense neighbourhoods. The latter results were further supported by Freedman (2013) who examined 3- to 5-year-old children during a picture-naming task and reported greater articulation accuracy for high PND compared with low PND words. For similar findings, see Sosa & Stoel-Gammon (2012).

While these selected studies already point to conflicting findings on the effects of PND on word production, Sadat et al. (2014) emphasised recently the inconclusive status by reviewing 19 studies that employed a picture-naming task across children and adults, and healthy and neurologically impaired subjects. Focussing on naming latency and accuracy, they cited findings that dense words inhibited the speed of word production in healthy speakers but facilitated naming accuracy in brain-damaged language impaired speakers (aphasics). Laganaro et al. (2014) attempted to tease apart these apparently opposite effects of PND by analysing the types of errors made during a picture-naming task in participants with aphasia. Laganaro and colleagues observed a facilitative effect with increasing density as the likelihood of producing nonwords or semantic substitutes for the target (e.g., *skirt* for *dress*) decreased. That is, high PND aids the production of the semantically correct word. But an

inhibitory effect was also found, since the likelihood of producing a phonologically related word to the target increased with increasing PND (e.g., *hat* for *cat*). Laganaro et al. (2014) suggested that many phonological neighbours provoke interfering effects which lead to an increased production of phonological neighbours in brain-damaged systems, and presumably to longer production latencies in non-brain-damaged systems, since high PND words slow down responses, with the result that the system achieves naming accuracy. However, this proposal is challenged by the studies that reported shorter production latencies for high PND compared with low PND words in healthy speakers, as stated above (Vitevitch, 2002; Baus et al., 2008).

It is not clear why the findings of PND in picture naming are inconsistent. One possible reason for the conflicting results regarding the effect of high PND may be the variation in experimental methods. For instance, participants in the studies conducted by Vitevitch (2002) and Baus et al. (2008) were familiarised with the picture material and their names. That is, participants experienced a delayed priming effect through exposure to the correct name prior to the naming task. Sadat et al. (2014) only used a practice trial with nonexperimental pictures to familiarise participants with the task, but not with the experimental stimuli. Arnold et al. (2005) included 18 children aged 3 to 5 years and 10 picture stimuli in their study. Bernstein Ratner et al. (2009) included 30 children aged 5 to 16 years and 44 pictures. In both studies, children did not see the pictures before the naming task but inconsistent outcomes

may have been caused by a difference in the number of trials, and by age differences between the two studies as well as within each study.

Taken together, existing behavioural results strengthen the suggestion that PND affects underlying processes of word production, by modulating their processing speed, thereby influencing naming latencies, and by affecting information selection, leading to misnomers. However, the contradictory results found within older and younger people do not allow a clear statement regarding the effects of high or low PND, that is, whether facilitative or inhibitory. Consequently, how PND affects word retrieval in typically developing language systems remains to be clarified. Revealing the effects of PND in typical language systems is essential because it provides a better understanding of how and where this phonological parameter modulates the ease of processing, and how such modulation may ultimately contribute to atypical language development. Although the findings point to distinct underlying sources where the effect of PND may occur (retrieval of word meaning and word form), behavioural data are eventually limited regarding the statement of affected processes preceding articulation onset. Whether phonologically dense words provide facilitation or inhibition during word production, and how word-form retrieval is ultimately affected, remain to be answered.

The following chapter will focus more closely on the cognitive processes involved in picture naming and will provide the foundation that allows the exposure of the effect of PND during word production.

Chapter 2

Picture naming

2.1 Main stages

Models of word production generally agree that before a speaker can articulate the name of a picture s/he has to go through the following main processes: visual processing, conceptual processing, lexical-semantic processing, phonological processing and articulatory preparation (Levelt, Roelofs, & Meyer, 1999), each of these terms being explained later in this chapter.

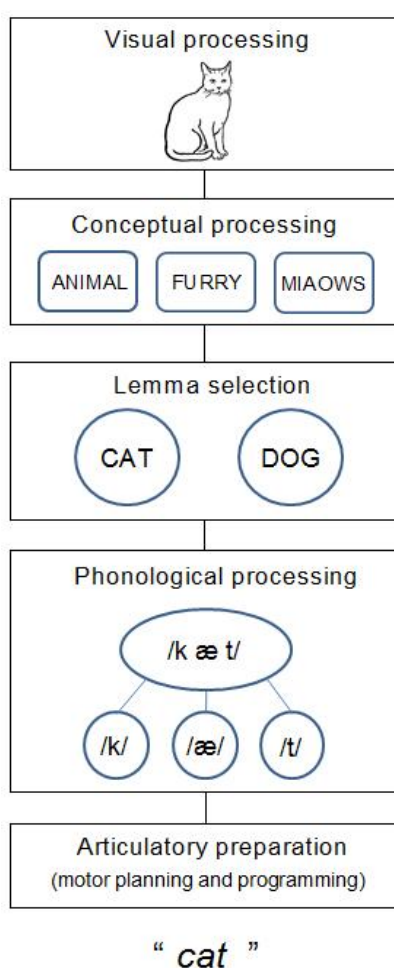


Figure 2.1. Schematic model of cognitive processes involved in picture naming exemplified by the word *cat*.

Visual processing involves the perception of the visual stimulus, which induces object recognition. The second process includes the activation of the corresponding concept, during which the semantic information of the intended word is specified, for example, *animal*, *furry*, *miaows*. Next a suitable word from the mental lexicon is retrieved. During the lexical-semantic processing the semantic information is converted to a meaningful linguistic representation (lemma). That is, the lemma that best matches the semantic information is selected from the mental lexicon, that is, *cat*. At this stage of word production, the speaker knows the meaning of the intended word but its form or sound properties are not yet specified. These will be encoded during phonological processing where a word's sounds or phonemes are retrieved and combined into syllables. For this example of *cat*, the phonological representation would be composed of the selected phonemes /k æ t/. The corresponding stress pattern is also assigned during this process. The output at this stage is an abstract phonological word that contains syllables and prosodic information (Indefrey, 2011). On the bases of this premotor phase, articulatory preparation that includes motor planning and programming takes place. During motor planning (also phonetic encoding) the phonological word is translated into specific motor plans, that is, specifications of movements regarding place and manner of articulation as well as timing. Articulatory plans then conduct motor programming, where muscle commands are specified, such as muscle tone, force or movement velocity (Van der Merwe, 2009). The final step is the actual execution of the speech

musculature to generate the acoustic signal. Figure 2.1 summarises the individual processes involved in picture naming. In the next section the time course of these processes will be outlined.

2.2 Time course in adults

As set out above, word production is a multilevel process where information is accessed within milliseconds given that two to three words per second are articulated in connected speech (Levelt et al., 1999). However, in recent years, findings from neuroimaging and high temporal resolution research have identified the temporal sequence of the underlying processes involved in word production, uncovering their availability in real time. An abundant corpus of research exists that used a variety of word-production tasks and experimental methods to characterise the order and duration of encoding processes (Abdel Rahman & Sommer, 2003; Camen, Morand, & Laganaro, 2010; Eulitz, Hauk, & Cohen, 2000; Laganaro, Morand, & Schnider, 2009; Laganaro, Python, & Toepel, 2013; Schmitt, Schiltz, Zaake, Kutas, & Münte, 2001; van Turennout, Hagoort, & Brown, 1997).

A comprehensive and systematic exploration of the temporal dynamics in word production was conducted by Indefrey and Levelt (2004). Based on neuroimaging and chronometric studies available at that time, the authors narrowed down the individual processing stages, leading to an estimation of the relative time course of single word production

during picture naming. Since then, the time course has been evaluated and updated by Indefrey (2011), integrating the results of recent electroencephalography studies using overt speech production tasks. Additional support for the time model comes from independent reviews focusing mainly on lexical–semantic and phonological processing (Ganushchak, Christoffels, & Schiller, 2011; Strijkers & Costa, 2011). Their temporal outlines corroborate Indefrey and Levelt, providing some reliability.

Based on findings from the meta-analyses, Indefrey and Levelt (2004; Indefrey, 2011) estimated the following onset times and durations for underlying processes of word production relative to picture presentation: object recognition (conceptual preparation) within the first approximately 200 ms, lexical–semantic retrieval (lemma selection) until about 275 ms, encoding of the phonological form approximately between 275 and 455 ms, followed by phonetic encoding and motor programming prior to articulation at approximately 600 ms after picture onset.

Indefrey and Levelt (2004; Indefrey, 2011) provide a detailed time map for word production based on broad data. Importantly, however, this estimation demands some additional consideration. Firstly, Indefrey and Levelt’s time course refers to an average naming latency of 600 ms, based on studies using repeated naming of the same pictures (Indefrey, 2011). But naming latency is influenceable and very variable, as documented in literature (Aristei, Melinger, & Abdel Rahman, 2011; Costa, Strijkers, Martin, & Thierry, 2009; Laganaro, Valente, & Perret, 2012). Besides,

Indefrey and Levelt's time course refers to the adult population, and children show longer production latencies than adults (D'Amico, Devescovi, & Bates, 2001; Laganaro et al., 2015), implying a temporal shift of the underlying processes. However, simply rescaling linearly the duration of all processing stages in the case of shorter or longer naming latencies seems to be questionable, as specific processes may take less or more time, depending on the experimental conditions (Laganaro et al., 2012, 2015). Secondly, following the general assumption of theoretical models that activity flows from concepts to lemmas to phonemes, Indefrey and Levelt's time frame indicates a sequential information retrieval. However, studies showed that different underlying processes can overlap, depending on task demands (e.g., Abdel Rahman & Sommer, 2003; Camen et al., 2010), suggesting parallel processing within specific time windows. This kind of information processing has been acknowledged by Indefrey (2011) who noted that:

Nonoverlapping time windows should, therefore, not be interpreted as indicating strictly serial processing stages. Specifically . . . the estimates for the onsets of phonological code retrieval and phonetic encoding are upper boundaries based on the evidence for the duration of the preceding stages and, hence, do not preclude earlier onsets. (Indefrey, 2011, p. 7)

Thus, the presented dynamics offer a hypothetical guideline and should not be considered too rigidly. Importantly, however, Indefrey and Levelt (2004; Indefrey, 2011) have temporally constrained theoretical models of language production by providing an estimated time course of the main processes involved in picture naming, thereby establishing a bridge between theory and neuroscientific evidence. Based on this foundation, Laganaro et al. (2015) recently complemented the chronometry by revealing the time course changes in younger populations, which will be inspected more closely in the following section.

2.3 Time course in children

The estimated time course provided by Indefrey and Levelt (2004; Indefrey, 2011) represents the timing of process durations based on adults' onset latencies. But given that production speed varies significantly between adults and children (e.g., D'Amico et al., 2001, Laganaro et al., 2015), this time course cannot be applied directly to the younger population. Children show longer response times relative to adults, indicating a latency shift of underlying processes. A linear rescaling of Indefrey and Levelt's durations seems questionable, since an increase in speed might not be attributable to all processing stages, but rather to specific operations. To reveal these suspected differences between children and adults, Laganaro et al. (2015) conducted an electrophysiological study recording brain wave data (described in greater

detail in Chapter 3) during overt picture naming in 7- to 8-year-olds, 10- to 12-year-olds, and adults. The behavioural results replicated earlier findings, with adults showing faster naming latencies (816 ms) than children, and 10- to 12-year-olds (1000 ms) having faster times than 7- to 8-year-olds (1146 ms). Importantly, the neurophysiological findings complemented those data.

By combining waveform analysis with topographic analyses (for a detailed description of the method see Laganaro, 2014) Laganaro et al. (2015) identified similar patterns of global electrophysiological activity at the scalp (topographies) across age groups. Importantly, stable topographies can be associated with specific periods of underlying information processing (Laganaro, 2014). Making use of this method, Laganaro et al. analysed the entire word production process from picture presentation to articulation onset. While they found topographic differences between children and adults in the early time period, the same sequence of stable scalp topographies across groups was observed, from about 200 ms in adults and about 300 ms in children up to articulation. Laganaro et al. attributed the early time-window, corresponding to the event-related potentials of P1 and N1 (evoked positive and negative peaks triggered by picture onset; described in detail in Chapter 3), to the prelinguistic operations of visuo-conceptual processes based on findings from previous electrophysiological studies. After visuo-conceptual processes, which extended to about 300 ms in children, four different topographies consistently appeared in all age groups, but with different

durations. Laganaro et al. related those to the main processes underlying word production. Thus it was presumed that children engage in lexical-semantic processing from about 290–300 ms after picture presentation. The duration of lexical-semantic processing decreased with increasing age. That is, adults showed shorter durations (until about 280 ms) than children, and 10- to 12-year-olds had shorter durations (until about 440 ms) compared with 7- to 8-year-olds (until about 480 ms). The subsequent period of stable scalp topography was related to word planning (phonological processing), which also differed in duration across age groups. Again, adults showed shorter durations (until about 420 ms) than children, and 10- to 12-year-olds had shorter durations (until about 640 ms) than 7- to 8-year-olds (until about 800 ms). For the two subsequent topographies only marginal differences in durations across groups were found. Given the accordance between the temporal dynamic of the adult data and Indefrey and Levelt's (2004; Indefrey, 2011) time course, Laganaro et al. followed their estimation, relating the last two processes to phonetic encoding and monitoring.

Taken together, Laganaro and colleagues demonstrated that quantitative changes in children's underlying processes are restricted to specific operations instead of an equal distribution throughout the word production process, concomitantly providing a time course for underlying processes in children. Table 2.1 summarises the estimated onset times and durations for the cognitive operations involved in picture naming for 7- to 8-year-old children.

Table 2.1. Estimated time windows (ms) of cognitive processes involved in overt picture naming for 7- to 8-year-old children.

Cognitive process	Time window
Object recognition and conceptual processing	0–290
Lexical–semantic processing (lemma selection)	290–480
Phonological processing	480–800
Phonetic encoding and articulation onset	800–1146

As with the time template provided by Indefrey and Levelt (2004; Indefrey, 2011) there is no assumption here that the complete process from picture onset to articulation is strictly temporally sequential. Although there is general agreement about the main processes involved in language production, different claims are made in the literature regarding the dynamics of these processes and their accessibility. The adopted model for this dissertation is the interactive activation account (Dell, 1986; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Dell, Schwartz, Nozari, Faseyitan, & Branch Coslett, 2013), where information of the intended word is retrieved through spreading activation. This framework will be explained in more detail in the following section.

2.4 Word access through spreading activation

In the context of interactive activation, as explained in detail by Dell and colleagues (Dell, 1986; Dell et al., 1997, 2013), not only will the target word be activated, but also words semantically and phonologically related to it (neighbours) because of shared components and the bidirectional spread of activation between the interconnected concept, word and phoneme levels. This mechanism will be illustrated in the following paragraph through the example of the word CAT (see also Figure 2.2).

Shared semantic information (e.g., animal, furry and chase) leads to the activation of related lemmas like DOG or MOUSE. All of these will activate their phonological representations, but for ease of explication, only the activation of CAT will be followed. When the phonological form of CAT becomes activated it will concomitantly activate the phonemes that constitute it (/k//æ//t/). However, due to the phonological overlap between the target and phonological neighbours (e.g., HAT, CAP and CAN) and the bidirectional activation flow, the latter ones also become activated (refer to Figure 2.2 for an illustration of the activation flow). The coactivated phonological neighbours in turn activate their phonemes, thereby increasing the activation of the shared target sounds and enhancing the phonological representation of /kæt/. Based on the bidirectional activation flow the correct lemma of CAT will be confirmed and selected. At the phoneme level the most activated sounds will be retrieved. Importantly, a target's amount of activation varies with the

number of neighbours, in that way influencing information retrieval. A target word with many neighbours will receive greater amounts of activation compared with words with only few neighbours, due to an amplified bidirectional activation flow, intensifying shared target information.

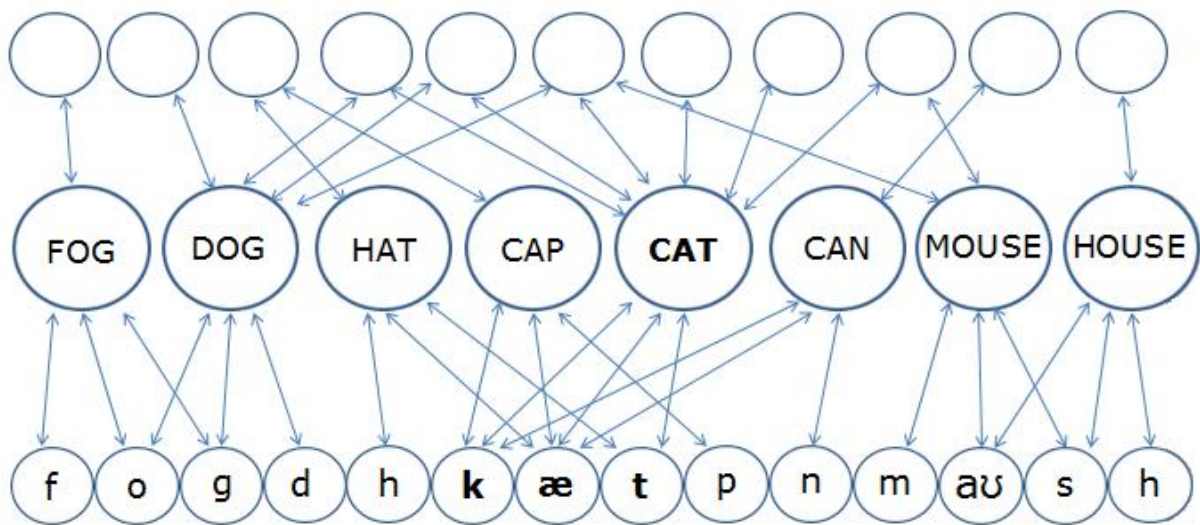


Figure 2.2. A simplified illustration of the word retrieval of CAT during naming based on spreading activation (top to bottom: semantic information, words, and phonemes).

Although the activation spreads between underlying processes in this model, Dell and colleagues (2013) showed that lexical-semantic and phonological processing can be dissociated during naming, making it possible then to capture and investigate these processes during word production, when taking their temporal sequence into account (Indefrey & Levelt, 2004; Indefrey, 2011; Laganaro et al., 2015).

Given the foundation provided by Indefrey and Levelt's (2004; Indefrey, 2011) chronometry, researchers have started to investigate the

word production process from an electrophysiological perspective to reveal the neurophysiological evidence underlying the verbal outcome. The following chapter will focus more closely on the electrophysiological approach and its potential to reveal underlying processing changes due to word-inherent properties.

Chapter 3

EEG method in the study of word production

3.1 Why use EEG to study word production?

The high temporal resolution technique of EEG and, more specifically, event-related potentials (ERPs) allow the investigation of high-speed processes like language production by going beyond behavioural measures. The use of EEG requires participants to wear electrodes placed onto the scalp to record the continuous electrical brain activity millisecond-by-millisecond throughout an experiment (for more detail, see Luck, 2014), thereby enabling temporally precise insights into underlying processes during their execution (Laganaro & Perret, 2011).

The electrical brain activity that accompanies information processing can be studied through ERPs. ERPs are a time-locked EEG activity and are calculated by averaging the recorded EEG activity of multiple repetitions of a given stimulus (e.g., presentation of a picture). This yields a "succession of positive and negative deflections (or peaks) which are labelled by their polarity (P = positive, N = negative) and order of occurrence (e.g., N1, N2) or point of occurrence poststimulus onset (e.g., N200, P300)" (Henderson, Baseler, Clarke, Watson, & Snowling, 2011, p. 88). The voltage deflections constituting the ERP reflect different underlying perceptual and cognitive mechanisms engaged in stimulus processing (Duncan et al., 2009). Importantly, their amplitudes index the extent of recruitment of neural resources to perform specific processes (Duncan et

al., 2009). Changes in the electrophysiological signal therefore indicate changes in the underlying perceptual or cognitive mechanisms. More specifically, an increase in ERP amplitude is assumed to indicate greater processing demands (e.g., Dufour, Brunellière, & Frauenfelder, 2013; Hunter, 2013; Obleser & Kotz, 2011). As a consequence, experimental manipulations allow the investigation of neurophysiological changes during stimulus processing, since differences in ERPs point to associated changes in processing efforts. With respect to word production, it is further possible to reveal the affected underlying mental operation(s), given the time template provided for picture naming (Indefrey & Levelt, 2004; Indefrey, 2011; Laganaro et al., 2015), enabling inferences to be made. Supportive evidence for this approach comes from recent EEG/ERP research that examined processing differences during language production by manipulating psycholinguistic variables that have been identified as predictors of word production. These studies will be surveyed in the following section.

3.2 Exploring the locus of linguistic variables during word production

Based on Indefrey and Levelt's (2004; Indefrey, 2011) time course, later investigations moved towards a hypothesis-testing approach instead of dissecting temporally the whole production system. More specifically, researchers started to examine the impact of psycholinguistic variables

(known to reliably affect behavioural responses) on cognitive processes. Variables that have been explored via EEG/ERP so far are word age of acquisition (Laganaro & Perret, 2011), word frequency (Strijkers, Costa, & Thierry, 2010; Strijkers, Holcomb, & Costa, 2011), cognate status (defined in the following paragraph; Christoffels, Firk, & Schiller, 2007; Strijkers et al., 2010), and name agreement (Cheng, Schafer, & Akyürek, 2010). By manipulating the materials (i.e., two subsets of items varying with respect to the specific variable being compared), those studies successfully identified processing differences during speech production that will be outlined in the following paragraphs.

Strijkers et al. (2010), for example, focussed in their ERP study on the effect of two variables during overt picture naming in adults: word frequency and cognate status. While word frequency refers to the degree of use of a given word, cognates are words with phonological overlap in two languages (e.g., the English–Dutch pair *milk* and *melk*). Both variables have been found to influence behaviour during picture naming. Pictures with high-frequency names show faster latencies than pictures with low-frequency names (Navarrete, Basagni, Alario, & Costa, 2006). Likewise, pictures representing cognates are named faster than pictures with noncognates (Costa, Santesteban, & Caño, 2005). Manipulating both variables, Strijkers et al. reported that ERPs to high-frequency words started to diverge from low-frequency ones around 180 ms after picture presentation (coinciding with the onset of P2). Low-frequency words evoked more positive-going amplitudes than high-frequency words.

Strijkers et al. found identical results when comparing noncognate versus cognate ERPs. Taking Indefrey and Levelt's (2004) time course into account, Strijkers and colleagues located the onsets of the effects to the initiation of lemma retrieval, thereby associating the P2 with the difficulty of lemma selection, "with more positive brain responses for the more difficult lexical conditions" (Strijkers & Costa, 2011, p. 10). Other ERP studies examining language production that reported effects attributed to lemma selection in a P2 range, are by Costa et al. (2009; semantic interference effects), Laganaro et al. (2012; processing speed effect) and Christoffels, Timmer, Ganushchak, and La Heij (2016; homophone effect).

However, the observed frequency and cognate effects reported by Strijkers et al. (2010) were not restricted to the P2 range. The authors found a similar modulation at the N2 range (240–320 ms postpicture onset), thereby relating the frequency and cognate effects to the subsequent process of phonological encoding. Similar findings were made by Christoffels et al. (2007), who also investigated the effect of cognate status during overt picture naming in adults. They observed ERP cognate effects between 275 and 375 ms after picture onset (coinciding with the N2 range), with more negative amplitudes for cognates compared with noncognates. Christoffels et al. attributed the cognate effect to phonological processing, based on Indefrey and Levelt (2004).

Taken together, these findings in adults demonstrated that the method of EEG/ERP was a suitable tool to explore underlying processing changes during speech production that result from word-inherent

properties. Importantly, those studies further started to align the modified ERP morphology to Indefrey and Levelt's (2004; Indefrey, 2011) chronometry (see Table 3.1). The electrophysiological approach is hence a promising way to investigate the effect of PND on word production and to reveal whether or not phonologically dense words provoke facilitation during phonological processing of the word form.

Table 3.1. Underlying processes involved in picture naming aligned with ERP components.

ERP component	Assumed processing stage
P1–N1	Object recognition/conceptual processing ^a
P2	Lexical–semantic processing
N2	Phonological processing

^a Laganaro et al., 2015.

So far, no EEG study exists that provides corresponding ERP data with respect to language production. However, such an approach has been successfully made in the context of spoken word recognition (Dufour et al., 2013; Hunter, 2013). Findings from these studies further underline the EEG/ERP approach, since they reveal the influential role of PND on the ease or difficulty with which a spoken word is accessed.

In contrast to word production, behavioural effects of PND with regard to word recognition are consistent. Words with many phonological neighbours are recognised more slowly and less accurately than words

with few phonological neighbours (Luce & Pisoni, 1998; Vitevitch & Luce, 1999). The theoretical assumption is that since spoken words are ambiguous at onset (e.g., /kæ/ could be the beginning of *cat*, *catch* or *cap*), “competitor words with similar onsets become active and compete for activation” (Mirman & Magnuson, 2008, p. 66). That is, phonologically dense words provoke the simultaneous activation of a larger number of words that must be inhibited, resulting in a slower recognition, whereas fewer neighbours lead to faster processing due to a reduced competition. Following this rationale, Dufour et al. (2013) investigated the PND effect in auditory word recognition with ERPs. Using a lexical decision task, adults had to decide whether the heard word was a nonword or word. Dufour et al. found greater negativities for the N400 for spoken words with high PND compared with low PND. The greater neural response was associated with the greater effort or difficulty to select the best word candidate. Although a different task, these results complement behavioural findings by demonstrating the sensitivity of neural structures to PND, indicating the potential impact of coactivated neighbours during word processing.

3.3 EEG method in the study of word production in children

To date, no EEG studies exist that investigated the impact of psycholinguistic variables on underlying processes involved in word production in children. Research on language production in the context of

EEG and ERP in younger people is in general very limited. However, this approach has been used in the recent past (Budd, Paulmann, Barry, & Clahsen, 2013, 2015; Laganaro et al., 2015). Corresponding findings demonstrate the successful usage of EEG/ERP in children during language production but also reveal developmental changes. Budd et al. (2013), for instance, recorded ERPs in 7- to 12-year-old children and adults while silently producing morphologically simple and complex words (e.g., *sang* vs. *walked*). The authors observed a similar electrophysiological response in children and adults to the effect of morphological complexity (larger negativities to complex words), indicating that both groups produce a specific brain response to a linguistic contrast (a similar pattern of ERP results was obtained by Budd et al., 2015). But Budd et al. (2013) also reported differences with respect to the overall pattern of the ERP waveforms, as children showed a longer lasting negativity and tended to have topographical differences compared with adults (similar results were found by Budd et al., 2015).

Developmental changes were also reported by Laganaro et al. (2015) who compared ERP differences between 7- to 8-year-olds, 10- to 12-year-olds and adults during picture naming. Although children and adults showed similar ERP waveforms, Laganaro et al. observed later peak latencies and larger amplitudes for children compared with adults.

Those observations in the context of language production are in line with findings from EEG studies investigating receptive language processing (e.g., Holcomb, Coffey, & Neville, 1992; Hahne, Eckstein, &

Friederici, 2004; Atchley et al., 2006), which reported similar neural responses across different age groups but differences regarding ERP magnitude and latency.

Taken together, the methods of EEG/ERP have been successfully applied in children to reveal processing differences during language production. Although the overall morphology of the ERP waveforms point to developmental differences, previous research showed similar brain responses across age groups in response to the same linguistic task, suggesting the use of the same cognitive processes in children and adults, a result that has been recently confirmed by Laganaro et al. (2015), who also demonstrated their quantitative changes during development (see Section 2.3).

Chapter 4

Pilot experiments: First attempt to explore the effect of phonological neighbourhood density on word production in adults and children—an ERP approach

4.1 Introduction

As outlined in Chapter 1, PND has been identified as a potential predictor of vocabulary development. As the number of words low in phonological density increases so does the size of the expressive vocabulary. However, late-talking children seem to be unable to make this transition, continuing to use phonologically dense words although their receptive vocabulary is composed of phonologically sparse words. Stokes (2014) proposed that the activation of the correct word form for phonologically sparse words may place higher demands for production than phonologically dense words. Unlike sparse words, dense words consist of phoneme strings that repeat frequently across many words, which may aid the generation of strong phonological representations, thereby facilitating word-form retrieval. Processing differences depending on PND level have been also reported in numerous behavioural studies across different age groups (as discussed in Chapter 1). Modulations in naming latencies and accuracies for words varying in PND point to affected underlying processes. However, the existing data is contradictory and do not provide sufficient evidence to answer the question as to whether phonologically dense words are facilitative during phonological processing of the word form.

While the behavioural measurements are informative in their own right, they do not fully capture cognitive processing activities that drive language performance. Investigating the influence of PND throughout the word-production process would advance our understanding of how the underlying processes are affected, in that way helping to elucidate the potential impairment in late-talking children. With confirmation of the time course of word production as set out in Chapter 2, it becomes possible to explore the relative effects of high and low PND on associated underlying processes. Earlier research has successfully shown that combining EEG/ERP with picture naming, when manipulating lexical properties, can provide more insights into affected linguistic processes and associated processing demands (as discussed in Chapter 3). Importantly, past research has started to align the temporal marker of phonological processing with the N2 wave of the ERP, time-locked to picture onset.

To date no ERP study exists that examined the effect of PND on the underlying process of phonological encoding during word production in children. This dissertation took a lead in addressing this issue, using EEG/ERPs to gain more insights into the impact of high and low PND on word-form retrieval. However, as no earlier research exists, pilot studies were conducted first. The goal of these was twofold. The testing of the feasibility of the methods and procedure was the main purpose. The validation of the new neurophysiological approach also required the inclusion of adult speakers (Experiment 1), before children could be approached (Experiment 2). In both experiments the same overt picture-

naming paradigm was applied, to verify that the procedure would yield the expected results.

At the same time, the pilot studies aimed to shed more light on the question as whether high PND words are facilitative or less demanding during phonological processing in speakers with healthy typical language systems. However, they only provide a first attempt to capture the impact of PND on phonological processing and do not provide conclusive evidence. Findings gave rise to methodical modifications of the experiment, in order to improve the neurophysiological outcome (Experiment 3 and Experiment 4).

4.2 Experiment 1

This experiment was the first attempt to investigate the effect of PND during phonological processing of word production. As outlined above, only behavioural data exist so far, providing only limited and contradictory results with respect to affected processes preceding articulation onset. In order to gain more detailed information about the influence of high and low PND on phonological processing, an ERP study was carried out. The validation of the new electrophysiological approach of studying PND required the inclusion of adults. The aim of the first pilot experiment was therefore to examine the effect of PND on phonological processing in adults.

Based on the theoretical framework of interactive activation of word production (Dell, 1986; see Section 2.4), where information retrieval depends on the target's activation level, high PND provides a facilitative effect during phonological processing. Supportive evidence for this theory comes from behavioural picture-naming studies (e.g., Freedman, 2013; Vitevitch, 2002; see Section 1.3). Previous ERP research investigating the effect of linguistic variables during picture naming associated the temporal marker of phonological processing with the N2 wave of stimulus-locked ERPs (see Section 3.2). Given that a reduced amplitude indicates a reduction in processing demands (see Section 3.1), the hypothesis was: Adults produce lower N2 peaks to high PND words than to low PND words. The corresponding research question was: Is there a significant difference in mean amplitude of N2 in adults between words of high PND and low PND?

4.2.1 Methods

Ethics approval

This project was approved by the University of Canterbury Human Ethics Committee (reference number HEC 2013/93). Participants gave signed consent before completing the study.

Participants

Participants were 34 monolingual English-speaking adults who were recruited via flyers emailed and posted across a university campus once ethical approval for the study had been gained. Participants who indicated interest were provided with information sheets and consent forms. Three subjects had to be excluded from the analyses due to an unacceptably high number of artefacts (see *ERP Data analysis* below). The remaining 31 participants (11 males) were aged between 19 and 33 years ($M=22.06$; $SD=3.19$) who reported no known history of visual, neurological or language-related problems on a preexperiment demographic questionnaire. All but one was right-handed. The participants gave their informed consent and received a \$10 voucher.

Material

The stimuli consisted of 40 monosyllabic English words and their corresponding coloured pictures retrieved from the colourized Snodgrass and Vanderwart picture set (Rossion & Pourtois, 2004) as well as from Google images that were not subject to copyright. Figure 4.1 shows one example of the used stimuli.



Figure 4.1. Example of picture stimuli used in the phonological neighbourhood density experiment.

The 40 words were selected from the MacArthur Communicative Development Inventories (CDI; Fenson et al., 1993). The CDI is an expressive vocabulary measure and comprises 680 words potentially known by the age of 2;6 years. Half of the items represented words with high PND ($n=20$) and the other half represented words with low PND ($n=20$). These words are listed in the Appendix A.

To identify phonological neighbours of each word, De Cara and Goswami's (2002) lexical database was used. This online database was chosen because it is appropriate for British English and because of its relatively large size (17.9 million words). De Cara and Goswami use two different definitions of PND, but only the +/- one phoneme metric (Luce & Pisoni, 1998) is used here, to align findings with previous research. Following the +/- one phoneme metric a phonological neighbour is defined based on the number of words which differ from the target word by a single phoneme substitution, deletion or addition. The median value was used to equally separate words into low or high neighbourhood conditions ($Mdn=21.5$). The average PND for low density words was 15.00 ($SD=3.39$) and for high density words it was 31.15 ($SD=5.75$). The neighbourhood sizes for the two conditions were significantly different from each other $t(38)=-10.82, p<.001$.

Set matching

To evaluate the potential effect of PND on speech production, high and low PND stimuli were balanced on the following variables: word

frequency, age of acquisition, imageability, index of phonetic complexity, phonotactic probability and semantic set size (see Table 4.1). In previous studies on speech production these variables were identified as influential predictors of naming performance (e.g., Alario et al., 2004; Vitevitch, Armbruster, & Chu, 2004).

Word frequency. The variable of word frequency was determined using De Cara and Goswami's (2002) lexical database. Their coding of lexical frequency corresponds to the Celex measure (Baayen, Piepenbrock, & Gulikers, 1995), that is, the occurrence per million words of adult speech within a 17.9 million spoken word corpus.

Age of acquisition and Imageability. Age of acquisition norms were taken from Cortese and Khanna (2008). Imageability was obtained from Cortese and Fugett (2004). Both norming procedures were based on the same word corpus consisting of 3,000 monosyllabic words. Age of acquisition ratings were made on a 1–7 scale (1: age 0–2 years; 7: age 13 years and older) by presenting words to adults and asking them to rate at what age they think they acquired the word (Cortese & Khanna, 2008). Imageability ratings were made on a 1–7 scale (1: low; 7: high) by asking adults to rate the words according to the ease or difficulty with which they arouse mental images (Cortese & Fugett, 2004).

Index of phonetic complexity (IPC). The IPC was identified using the scoring protocol for eight phonetic factors developed by Jakielski (2000). Each word was transcribed phonetically using the International Phonetic Alphabet (IPA: reference) and then scored according to the eight phonetic

factors. Scoring was performed independently by the author and a speech and language pathologist to assure reliability ($r=.94$). The IPC coding procedure is shown in Appendix B and the IPC scores for the word stimuli are listed in Appendix D.

Phonotactic probability. Phonotactic probability combines two kinds of phonological frequency information, that is, biphone frequency (BF) and positional segment frequency (PSF). BF defines segment-to-segment cooccurrence probability of sounds within a word whereas PSF refers to how often a particular segment occurs in a certain position in a word (Vitevitch & Luce, 2004). To the author's knowledge no online database is available to provide such detailed measures of phonotactic probability for British English. However, following the principle that the varieties of English do not vary too much, taking account of the /r/ coloured vowels used in the USA English, Vitevitch and Luce's Phonotactic Probability Calculator (2004) was applied to calculate BF and PSF (for detailed information about the usage of the Phonotactic Probability Calculator see Vitevitch & Luce, 2004).

Semantic set size. This variable was retrieved from the database of the University of South Florida Free Association Norms (Nelson, McEvoy, & Schreiber, 1998). Data were collected by having adults writing down the first word that came to mind that was meaningfully related to a given word. The number of responses across participants comprised the word's semantic set size. For one item of the word stimuli (bib) no semantic set size could be retrieved since there is no corresponding data available.

The differences in word frequency, age of acquisition, imageability, index of phonetic complexity, phonotactic probability and semantic set size were assessed using independent *t*-tests. There was no significant difference between the high PND and low PND words for all of these matching variables (see Table 4.1).

Table 4.1. Mean properties of pictured word stimuli, along with standard deviations.

	Neighbourhood Density		<i>t</i> -Value (<i>df</i> =38)	<i>p</i> -Value
	High <i>M</i> (<i>SD</i>)	Low <i>M</i> (<i>SD</i>)		
PND	31.15 (5.75)	15.00 (3.39)	-10.82	.000
Word frequency	30.95 (33.85)	31.45 (31.21)	0.05	.96
Age of acquisition	2.66 (.28)	2.66 (.40)	-0.05	.96
Imageability	6.56 (.34)	6.41 (.47)	-1.19	.24
Phonetic complexity	2.70 (.80)	2.70 (.92)	0.00	>.99
Biphone frequency	.007 (.004)	.007 (.006)	-0.28	.78
Positional segment frequency	.16 (.05)	.14 (.04)	1.32	.19
Semantic set size ^a	13.15 (4.31)	14.47 (5.02)	0.89	.38

Note. PND = phonological neighbourhood density.

^a No semantic set size for one word, *df* = 1,37.

Procedure

ERP experiment

Participants were tested individually in a quiet and dimmed room sitting approximately 60 cm in front of a computer monitor, which was placed level with the participants' gaze. The experimental task was an overt picture-naming task. To familiarise participants with the experiment the task began with 20 practice trials, followed by 40 experimental trials (20 high PND and 20 low PND items). None of the practice stimuli were used as experimental stimuli. Participants performed accurately on these practice trials, indicating that they understood the task well enough to progress onto the experimental trials.

The presentation of the trials was controlled by the E-Prime software (E-Studio; version 2.0, Psychology Software Tools, Inc., Pittsburgh, PA). A trial had the following structure: It began with the presentation of a black fixation cross in the middle of a white screen, which was shown for 500 ms. Then the picture appeared at the centre of the screen for 1000 ms. Picture stimuli were displayed in a constant size of 9*9 cm on a white background. Participants were instructed to overtly produce the word corresponding to the picture as quickly and accurately as possible. A blank inter-trial-interval was jittered randomly from 1500 ms to 2500 ms. Within the experimental task all 40 items appeared once in random order for every participant.

Participants received instruction on how to reduce eye blinks and muscle activity to avoid artefacts. Misnomers of the stimuli were noted by

the experimenter. The entire experiment lasted about 45 minutes including instructions and placement of the electro cap.

EEG acquisition and preprocessing

Using a BioSemi Active Two amplifier system (Biosemi V.O.F. Amsterdam, Netherlands), the EEG was recorded from 32 pin-type Ag-AgCl sintered Active-electrodes, with a Common Mode Sense (CMS) active electrode and a Driven Right Leg (DRL) passive electrode as reference and ground, respectively (<http://www.biosemi.com/faq/cms&drl.htm>). Electrodes were placed in standard International 10–20 System locations. Electrooculograms (EOG) were recorded from individual electrodes placed next to the left and right eye for horizontal eye movements and above and below the left eye for vertical eye movements. Two other electrodes were placed on the left and right ear lobes for off-line referencing. In order to detect response activation another two electrodes were used to measure the neuromuscular or electromyographic activity (EMG) associated with the onset of muscle movements for articulation (McArdle, Mari, Pursley, Schulz, & Braun, 2009). EMG was recorded from the vermilion boarder of the upper lip and under the chin. Signals were sampled at an analog-to-digital conversion rate of 1024 Hz with band-pass filters set between 0.16–268 Hz.

Offline EEG analyses were conducted using the BrainVision Analyzer software (Brain Products GmbH, München, Germany). EEG data were re-referenced to the average of the left and right earlobe channels. The four

individual EOG channels were converted to a vertical and a horizontal bipolar EOG. The EEG was filtered with a .01–20 Hz bandpass filter (slope: 24 dB/octave) using also a notch filter (50 Hz). The signal was then segmented into 1800-ms-long epochs starting 200 ms prestimulus until 1600 ms poststimulus. Epochs were baseline corrected using the average amplitude between 200 ms prestimulus onset and stimulus onset. Eye movement artefacts were removed utilizing an eye regression routine (Segalowitz, 1996). In addition, segments with amplitude voltages exceeding $\pm 100\mu\text{V}$ on any of the investigated EEG channels or the bipolar EOG channels were eliminated. This artefact rejection process was applied from stimulus onset until 800 ms poststimulus. The shorter period for artefact rejection was chosen in order to preserve segments for the individual average. Given that the paradigm was an overt naming task, motor artefacts, predominantly present at later time periods, would have caused segment reduction. Segments representing erroneous trials (i.e., wrong responses, absent reactions or autocorrections) were removed prior to averaging the EEG signals. Subjects who did not reach the criterion of $\geq 60\%$ correctly answered trials per condition after rejection of eye-blinks and artefacts were excluded. For each participant averaged ERPs for high PND and low PND segments were calculated.

Data analysis

In order to complement the neurophysiological data, the behavioural data were also analysed.

Behavioural data

Word errors

The given responses by the participants were examined for speech errors. There were three types of error responses: absent reaction, autocorrection and wrong responses (i.e., participants produced words other than the intended target word). The first two errors types were excluded from further error analysis (0.1%). The total of wrong responses was 3.8%. A paired *t*-test was carried out to compare the amount of errors between the high and low PND condition.

Reaction time

Behavioural data analysis was based on the EMG measurement. Therefore, reaction time (RT) refers here to the time interval between the onset of the picture and the onset of speech movement.

Within the BrainVision Analyzer software (Brain Products GmbH, München, Germany) the two individual channels recorded from the vermilion boarder of the upper lip and under the chin were converted to one EMG channel for each participant. The EMG data were further processed through the software programme of Matlab (MATLAB and Statistics Toolbox Release 2013a, The MathWorks, Inc., Natick,

Massachusetts, United States). More specifically, a Matlab routine was used which allowed for the automatic marking of the RT within a specified EMG time window, encompassing 800 ms prepicture onset and 3000 ms postpicture onset (Figure 4.2). RT was quantified on a trial by trial basis for each participant and defined as the first location where the μV value was more than 3.5 SD above the mean μV value in reference to the baseline (corrected time period starting 1100 ms prepicture onset and ending 100 ms before picture onset). The Matlab routine allowed for visual inspection of the EMG signals and, when necessary, allowed for manual scoring. All RT measurements were carried out by the author. Importantly, however, the RT was marked without knowing to which of the two conditions the EMG segment belonged and which trial number was presented. Only trials where the intended target word was produced were considered for the statistical analysis. Trials with RT shorter than 350 ms (3.3%) were also excluded (e.g., Laganaro et al., 2015; Porcaro, Medaglia, & Krott, 2015). Paired *t*-tests were used to examine statistical differences.

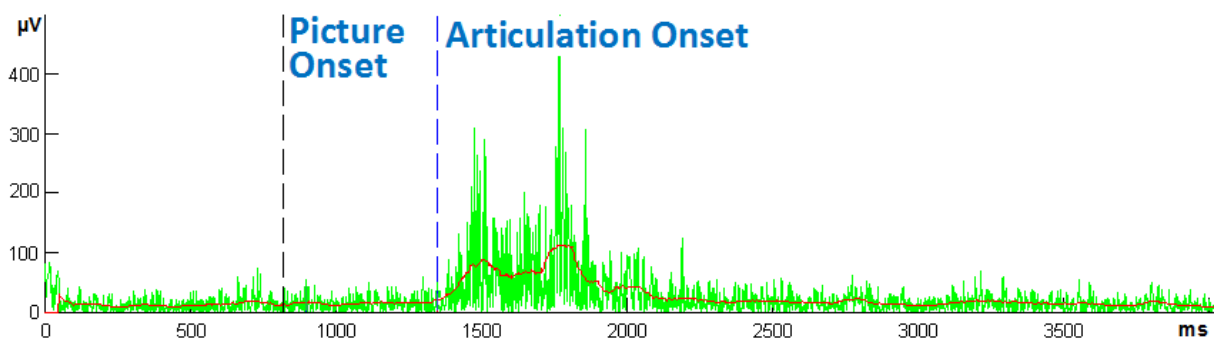


Figure 4.2. Identification of articulation onset in an EMG signal.

ERP data

Three participants had to be excluded from the ERP analysis because of a high number of artefacts. In total, ERP analyses were based on 31 participants. Based on visual inspection of the grand average waveforms, five time windows containing visible peaks were selected: 0–120 ms (P1 peak), 80–210 ms (N1), 130–220 ms (P2), 200–390 ms (N2) and 300–600 ms (P3). The peak labels are used as descriptive labels. The ERP data were processed using a Matlab routine which allowed for automatic scoring and visual inspection of ERP peaks, and further allowed for manual scoring, when necessary (Gavin, 2014). Within each defined time window the maximum signal deviation from baseline was automatically selected by the Matlab routine. The baseline-to-peak amplitudes as well as peak latencies for the P1, N1, P2, N2, and P3 were obtained from each averaged ERP waveform. All peaks were measured at three midline electrode sites that are Pz, Cz and Fz. These electrode sites were chosen based on past research findings that reported cognate effects over parietal and frontal sites (Christoffels et al., 2007; Strijkers et al., 2010). Since no hypothesis regarding lateralisation was made, the midline electrodes were investigated. All ERP measurements were carried out by the author.

The statistical analysis was as follows. In each time window, mean amplitudes were compared using two-way repeated measures ANOVA, with PND (high and low) and Electrode site (Pz, Cz and Fz) as variables. Mauchly's test was used to evaluate the assumption of sphericity and if the test was significant, the Greenhouse–Geisser adjustment was applied.

If the two-way ANOVA showed a significant main effect or interaction involving PND (with alpha set to .05), further analyses were conducted using Tukey's *a priori t*-test (Kirk, 1995).

Additionally, in order to reveal relations between different stages of processing, correlation analyses were performed on individual mean peak latencies of low PND or high PND with the corresponding individual mean RTs.

4.2.2 Results

Behavioural data

Word errors

There was no significant difference in the number of word errors (i.e., wrong response) elicited by high PND words ($M=.74$; $SD=.73$) and low PND words ($M=.84$; $SD=.93$), $t(30)=.55$, $p=.59$.

Table 4.2. Mean and standard deviations of articulation onsets in ms for high and low PND picture names in adults.

	<i>M</i>	<i>SD</i>
High PND	593.88	112.31
Low PND	649.98	149.97

Note. PND = phonological neighbourhood density.

Reaction time

Paired *t*-tests showed that words residing in dense phonological neighbourhoods were named significantly faster than words residing in sparse neighbourhoods, $t(30)=2.51$, $p=.018$, $d=.41$ (see Table 4.2).

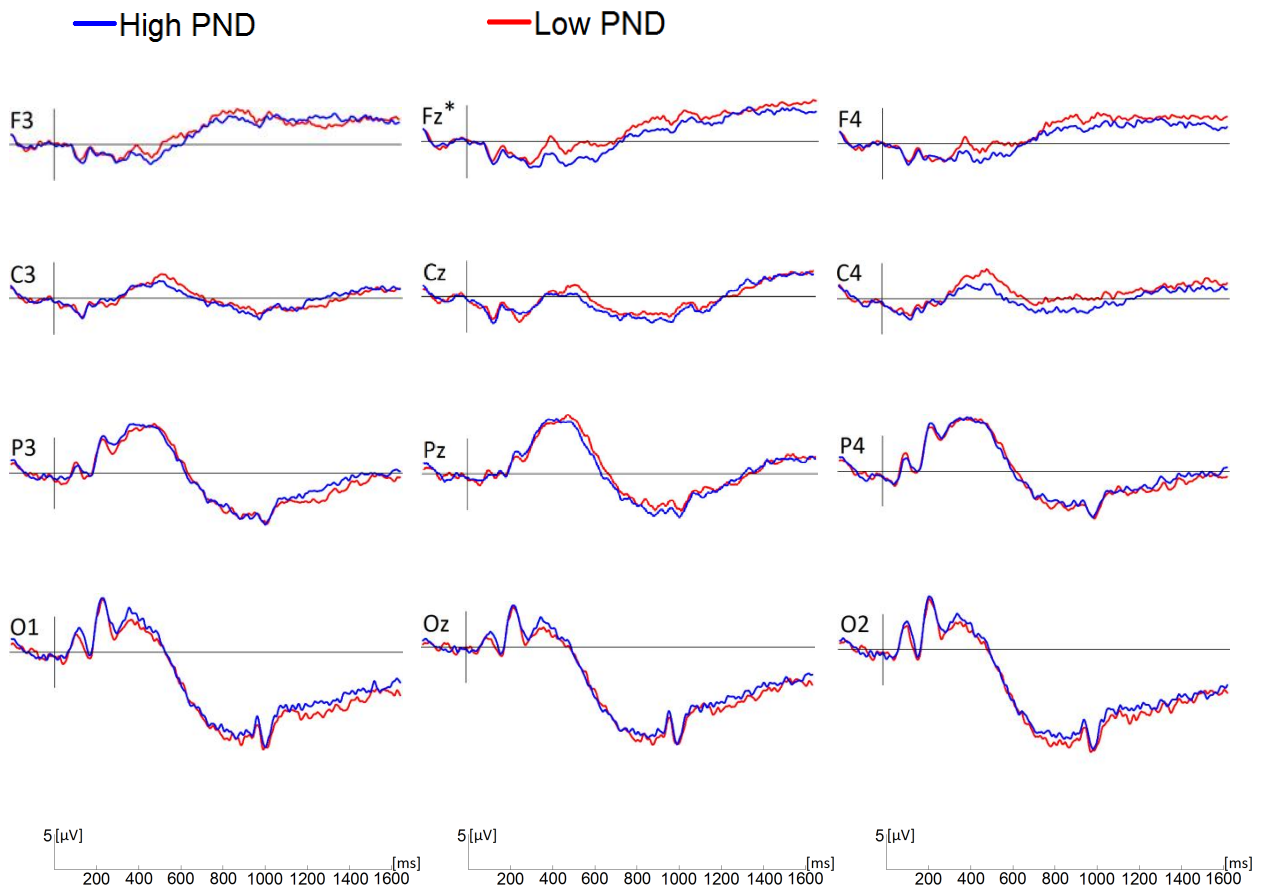


Figure 4.3. Grand averages of ERPs to pictures with different levels of Phonological Neighbourhood Density (PND) in adults. High PND ERPs are represented by a blue line and low PND ERPs by a red line. To visualise the emergence of the PND effect anterior, central and posterior scalp locations are shown. The electrode site marked by an asterisk is shown in an extended view in Figure 4.4. Positivity is plotted upwards.

ERP data

In Figure 4.3 grand average ERP waveforms are displayed to visualise the PND effect of each condition. Grand averages indicated that ERPs between the naming of high and low PND pictures started to differ at about 300 ms after stimulus onset at frontal electrode sites, which was further supported by the statistical analyses. The electrode site marked by an asterisk is shown in an extended view in Figure 4.4.

Early time windows (P1: 0–120 ms and N1: 80–210 ms):

The only main effect found in the early time windows was for Electrode site (P1: $F(1.65, 49.49)=7.01, p=.004$; N1: $F(1.46, 43.73)=8.59, p=.002$). There was neither a main effect of PND (P1: $F(1, 30)=.13, p=.719$; N1: $F(1, 30)=.29, p=.592$) nor an interaction between PND and Electrode site (P1: $F(1.55, 46.63)=.16, p=.799$; N1: $F(1.54, 46.29)=.24, p=.730$).

Later time windows (P2: 130–220 ms, N2: 200–390 ms and P3: 300–600 ms):

The only significant main effect in these time windows was for Electrode site (P2: $F(1.29, 38.86)=23.13, p<.001$; N2: $F(1.37, 41.08)=20.95, p<.001$; P3: $F(1.34, 39.84)=40.56, p<.001$). There was no main effect of PND (P2: $F(1, 30)=.01, p=.942$; N2: $F(1, 30)=.65, p=.427$; P3: $F(1, 30)=.38, p=.541$). But a significant interaction between PND and Electrode site was shown in the P3 time window, $F(1.39,$

41.71)=3.68, $p=.049$ (P2: $F(1.53, 46.00)=2.15$, $p=.139$; N2: $F(1.24, 37.14)=2.52$, $p=.114$). Running the Tukey's *a priori t*-test revealed that low PND pictures showed a significantly larger positivity than high PND pictures at the frontal site, $t(150)=2.39$, $p<.01$, $d=.29$, while there was no differential effect on the P3 amplitudes at central ($t(150)=-.43$, $p>.05$) and parietal sites ($t(150)=-.35$, $p>.05$). Table 4.3 summarises the mean peak amplitude of P3 for both experimental conditions at all three electrode sites. Figure 4.4 displays the grand average waveforms for electrode site of Fz.

Table 4.3. Mean peak amplitude (in μV) of P3 for each experimental condition at midline electrodes, along with standard deviations.

	High PND	Low PND
	<i>M (SD)</i>	<i>M (SD)</i>
<i>P3 amplitude</i>		
Fz	.91 (5.09)	2.18 (6.49)
Cz	3.93 (4.21)	3.70 (5.66)
Pz	10.74 (4.99)	10.56 (4.99)

Note. PND = phonological neighbourhood density.

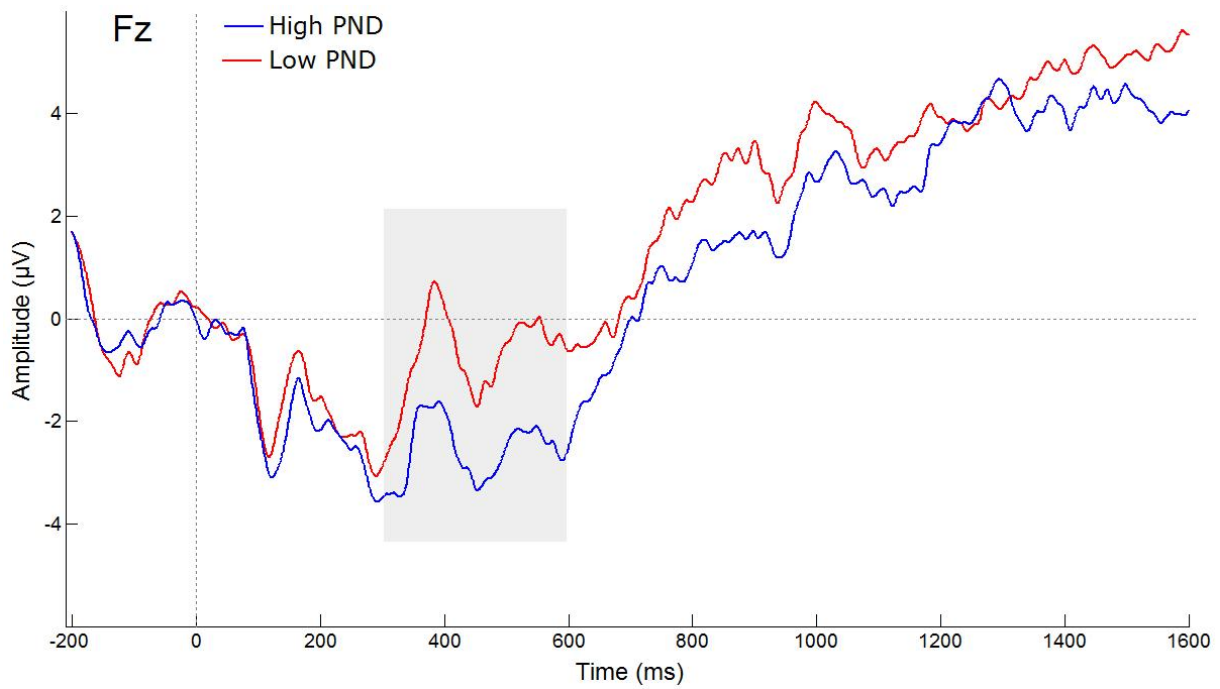


Figure 4.4. Grand average waveforms for electrode site Fz for pictures of high and low Phonological Neighbourhood Density (PND). High PND is represented by a blue line and low PND by a red line. The time window significantly affected by PND level is indicated, 300–600 ms (P3).

Correlation Analyses

To understand and differentiate the underlying processing of the P3 range, bivariate correlation analyses were carried out. No significant ($p > .05$) Pearson's product-moment correlations between the individual mean peak latencies of low PND (Pz: $r = .04$; Cz: $r = .22$; Fz: $r = .12$) or high PND (Pz: $r = .05$; Cz: $r = -.03$; Fz: $r = .01$) with the corresponding individual mean RTs were present.

4.2.3 Discussion Experiment 1

In the present experiment ERPs and behavioural data were measured while healthy English-speaking adults overtly named pictures with high and low PND. The aim was to investigate the effect of PND on phonological processing, by shedding more light on the question of whether phonologically dense words are facilitative and less demanding during phonological processing of the word form. At the same time this pilot experiment with adults was conducted to demonstrate proof of concept for investigating PND using EEG/ERP before approaching younger people.

As the N2 wave had been associated with phonological processing in previous ERP studies using picture naming, it was predicted that adults produce lower N2 peaks to high PND words than to low PND words.

Overall, adults named high PND pictures with the same accuracy as low PND items. However, they produced pictures significantly faster when names resided in dense neighbourhoods compared with sparse neighbourhoods, which is in accordance with prior behavioural findings that reported faster response times for high PND words (Baus et al., 2008; Vitevitch, 2002). Naming latencies therefore suggest an ease of processing for high PND words. Electrophysiological data further confirmed these results.

The peaks of the ERP waveforms appeared in the following time scale: P1 at around 80 ms, N1 at around 130 ms, P2 at around 180 ms,

N2 at around 250 ms, and P3 at around 400 ms. The observed peaks appeared in a similar time range to those reported in past ERP studies using picture naming in adults (e.g., Strijkers et al., 2010).

PND did not significantly modulate N2. Although grand average ERP waveforms for electrode site Cz indicated amplitude differences for N2, these modulations were not statistically significant. However, significant differences between high and low PND words were observed for the P3 range. For high PND words the P3 amplitude was lower than for low PND words. Though apparent at the central site, these amplitude modulations were statistically confined to the frontal electrode.

These ERP results did not confirm the original prediction, since no significant differences in mean amplitude of N2 between words of high and low PND could be found. However, the present results showed lower P3 peaks to high PND words compared with low PND ones, indicating differences in processing demands in favour of the hypothesis. Importantly, P3 peaked at around 400 ms postpicture onset, falling in a time period that also corresponds to phonological processing (between 275 and 455 ms), based on the estimated time course of overt picture naming provided by Indefrey and Levelt (2004; Indefrey, 2011). Supportive evidence for an influence of phonological similarity on the later P3 range comes from prior ERP research investigating the effect of cognate status during picture naming in adults (Strijkers et al., 2010). As explained in the introduction, cognates are words that are phonologically similar but belong to different languages (e.g., the English–Dutch pair

milk and *melk*). Strijkers et al. (2010) observed a cognate effect on three consecutive time windows, 160–240 ms (P2), 240–320 ms (N2) and 320–420 ms (P3) postpicture onset. Noncognates evoked greater amplitudes compared with cognates. The effect was widely distributed over the scalp but reached its maximum at posterior and right-frontal sites. While Strijkers et al. aligned the P2 window with lexical–semantic processing, and the N2 window with phonological encoding, they were reserved regarding the P3 window, since amplitude modulations of P3 could partially reflect early stages of motor preparation, masking linguistic processes (e.g., Ackermann & Riecker, 2004; Porcaro et al., 2015; Shuster & Lemieux, 2005). The data of the present experiment showed no correlations between EMG-based reaction times and P3 peak latencies, suggesting an effect related to the premotor phase, that is, phonological processing. Further supporting evidence for this assumption comes from past neuroimaging and ERP research (e.g., Georgiewa et al., 2002; Papoutsi et al., 2009; Vihla, Laine, & Salmelin, 2006). Georgiewa et al. (2002) used functional magnetic resonance imaging (fMRI) and ERP techniques to investigate phonological processing in dyslexic and normal-reading children, who silently read words and pronounceable nonwords. Dyslexia is a reading disorder associated with phonological processing deficits (Snowling, 2000). Results of the fMRI analysis revealed differences between both groups in the brain activation in the left inferior frontal gyrus. The ERP data showed differential activation between the groups at left frontal electrodes between 350 and 600 ms (P3) poststimulus onset

for the nonwords condition (Georgiewa et al., 2002). These findings further support the theory that the amplitude differences of P3 in the present experiment can be ascribed to brain responses associated with phonological processing.

Adults showed lower P3 peaks to high PND than to low PND words, suggesting lower processing demands during the word-form retrieval of phonological dense words (e.g., Dufour et al., 2013; Hauk & Pulvermüller, 2004; Hunter, 2013; Obleser & Kotz, 2011). These findings can be explained through the interactive activation account (Dell, 1986). For a word with many phonological neighbours, many shared phonological representations become activated because of their overlap in sounds. Importantly, these phonological neighbours will in turn activate their phonemes, thus contributing to the target's activation since all but one of the target's phonemes receive activation. High PND words will consequently cause a stronger activation compared with low PND words, owing to the larger number of neighbours, with dense words benefiting from multiple activations during processing (Chen & Mirman, 2012). Presumably the increased activation occurs as a process of distributed neural processing and lower processing demand. The correct word form will be boosted, thereby facilitating phonological retrieval.

For low PND words a similar process will unfold, but given the reduced phonological connectivity, the process of spreading activation is generally lower, resulting in a lower activation level of the target's phonological form. As a consequence, processing resources may increase

in order to access the required information (Prabhakaran, Blumstein, Myers, Hutchison, & Britton, 2006). The lower activation level may also slow down word-form retrieval, affecting subsequent articulatory preparations, leading to slower naming latencies, as seen in the present experiment. Conversely, the increased phonological overlap for high PND words accelerates information retrieval, resulting in a faster initiation of articulation. Given the accordance of electrophysiological and behavioural data, the results further indicate that PND affects neural processes that directly influence articulation onsets.

The functional characteristics of P3 have been explored abundantly in past EEG research, thereby showing that the frontal P3 can be related to involuntary attention (e.g., Escera, Alho, Winkler, & Näätänen, 1998; Yamaguchi & Knight, 1991). Taking these findings into account, the present P3 differences may partially reflect the attentional resources needed for naming pictures that vary in PND level. For instance, due to the increased multi-directional activation for dense words during phonological processing, the target's label is identified and retrieved more easily. Alternatively, the lower activation of phonological information for sparse words might intensify the search for the name, ultimately increasing the attentional demand to connect the picture with its label. Additional research is needed to further explore the processes that underlie P3 generation.

There are limitations to the present findings that should be acknowledged. The present experiment is limited because it was a

feasibility study with a small number of trials (20 stimuli per condition). It could be that P3 amplitude differences are the consequence of latency jitter caused by stronger variations registered in the late time window. Replication of the experiment with an increased number of trials would provide more stable ERPs and may produce different results or reveal an even stronger effect of PND on phonological processing. In the current study, PND had a small effect in adults, which might indicate that PND is less influential compared with other linguistic variables found to affect the word production process (Cheng et al., 2010; Strijkers et al., 2010; Laganaro & Perret, 2011). However, this needs to be clarified in additional research.

In conclusion, neurophysiological data from adults indicate that dense words are less demanding during phonological processing compared with sparse words, as high PND words evoked lower peak amplitudes than low PND. However, these amplitude modulations were observed for P3, inconsistent with the original hypothesis that predicted amplitude differences for N2, based on previous research associating the N2 wave with phonological processing. Still, the present P3 peaked at about 400 ms postpicture onset and can also be related to phonological processing based on the chronometry of picture naming previously provided for adults.

The facilitative processing of high PND words was further supported by the behavioural data, showing shorter naming latencies to phonologically dense words compared with phonologically sparse words.

The present electrophysiological results demonstrated proof of concept for exploring the effect of PND using EEG/ERP. Given these findings, children could be approached to test feasibility and verify that the procedure yields the expected outcomes. The same experiment was conducted with school-age children, and will be described in the following section.

4.3 Experiment 2

Based on the outcome of Experiment 1, the second pilot study aimed to test the feasibility of investigating the effect of PND using EEG/ERP in children. At the same time, this study was a first attempt to gain more insights into the impact of high PND during phonological processing in children. Based on the results of Experiment 1 and findings from previous ERP research reporting similar electrophysiological responses to the effect of linguistic manipulations in adults and children (see Section 3.3), the hypothesis was:

Children produce lower P3 peaks to high PND words than to low PND words.

The corresponding research question was:

Is there a significant difference in mean amplitude of P3 in children between words of high PND and low PND?

The methods were in general similar to those reported in Experiment 1 and will therefore not be repeated in the following sections. Children underwent the same overt picture-naming task with the same stimuli material. Except when specified, all procedures and analyses were identical to those conducted in Experiment 1. Please refer to Section 4.2.1 for a detailed description of stimuli set, procedure and analyses.

4.3.1 Methods

Ethics approval

This project was approved by the University of Canterbury Human Ethics Committee (reference number HEC 2013/134). Children and their parents gave signed consent before completing the study.

Participants

Thirty children aged between 7;0 and 7;9 were recruited from a database of volunteer families contacted via mail and through word of mouth. Ten children were excluded from the analyses due to high movement artefacts and error rates (see *ERP Data analysis* below). The remaining 20 children had a mean age of 7;4 with a standard deviation of 3 months. Of these, eight were females. All but two participants were right-handed (defined by writing hand). All participants were required to meet the following inclusion criteria: (a) native, monolingual speakers of English; (b) were identified as typically developing; (c) no history of

speech, language, or hearing impairment; (d) no serious (chronic) health problems (not taking medication); and (e) normal or corrected to normal vision. Parent report on a questionnaire was used to confirm that children met all of these conditions. To ensure that all children performed within normal limits of their age regarding vocabulary knowledge, the standardised *Receptive One-Word Picture Vocabulary Test* (ROWPVT-4; Brownell, 2011) was administered to all participants. Word recognition scores were within normal limits in all children (mean standard score = 113.60, $SD = 12.18$). Children received a small gift and a 10\$ voucher for their participation.

Material and Procedures

Stimuli and Procedures (including EEG acquisition and preprocessing) were in general identical to those in Experiment 1. The only change in the ERP experiment concerned the blank inter-trial-interval (ITI), which was prolonged and jittered randomly from 2500 ms to 3500 ms instead of 1500 ms to 2500 ms. Observations of the children during a prior test run when using the shorter ITI showed increasing pressure on the children, which led to tension and omissions in picture naming. Participants performed correctly during the practice part and could progress onto the experimental trials. Although De Cara and Goswami's (2002) online database, which was used to identify phonological neighbours, relies on data from adults, child and adult lexical corpora have been reported to be positively correlated (e.g., Storkel & Hoover, 2010).

Data analysis

Behavioural data

The behavioural analyses were identical to Experiment 1.

Word errors

For both experimental conditions the following error types existed: absent reaction, autocorrection and wrong responses, that is, words other than the intended target. The total of absent reactions and autocorrections was 0.4% and 6.5% for wrong responses.

Reaction time

All trials showed latencies longer than the 350 ms criterion.

ERP data

The ERP analyses were identical to those described in Experiment 1 but the time windows were shifted: 0–140 ms (P1 peak), 120–250 ms (N1), 180–380 ms (P2), 300–490 ms (N2) and 490–800 ms (P3). Ten participants did not reach the criterion of $\geq 60\%$ correctly answered trials per condition after rejection of eye-blinks and artefacts and were excluded. The ERP analyses were based on 20 participants. The statistical approach was the same as outlined in Experiment 1.

4.3.2 Results

Behavioural data

Word errors

The conducted paired *t*-test revealed no significant difference in the elicitation of word errors (i.e., wrong responses) between the high PND ($M=1.10$; $SD=1.02$) and the low PND ($M=1.50$; $SD=1.36$) condition, $t(19)=1.25$, $p=.23$.

Reaction time

The mean naming latency of high PND picture names was not statistically different from the naming latency of low PND picture names, $t(19)=-.89$, $p=.39$ (see Table 4.4).

Table 4.4. Mean and standard deviations of articulation onsets in ms for high PND and low PND in 7-year-olds.

	<i>M</i>	<i>SD</i>
High PND	714.24	71.14
Low PND	699.02	68.01

Note. PND = phonological neighbourhood density.

ERP data

Figure 4.5 shows the general structure of the children's ERP pattern that was characterised by prominent negativities. The grand averages indicated differences in amplitudes already for very early ERP waves,

which was further supported by the statistical analyses. The electrode site marked by an asterisk is shown in an extended view in Figure 4.6.

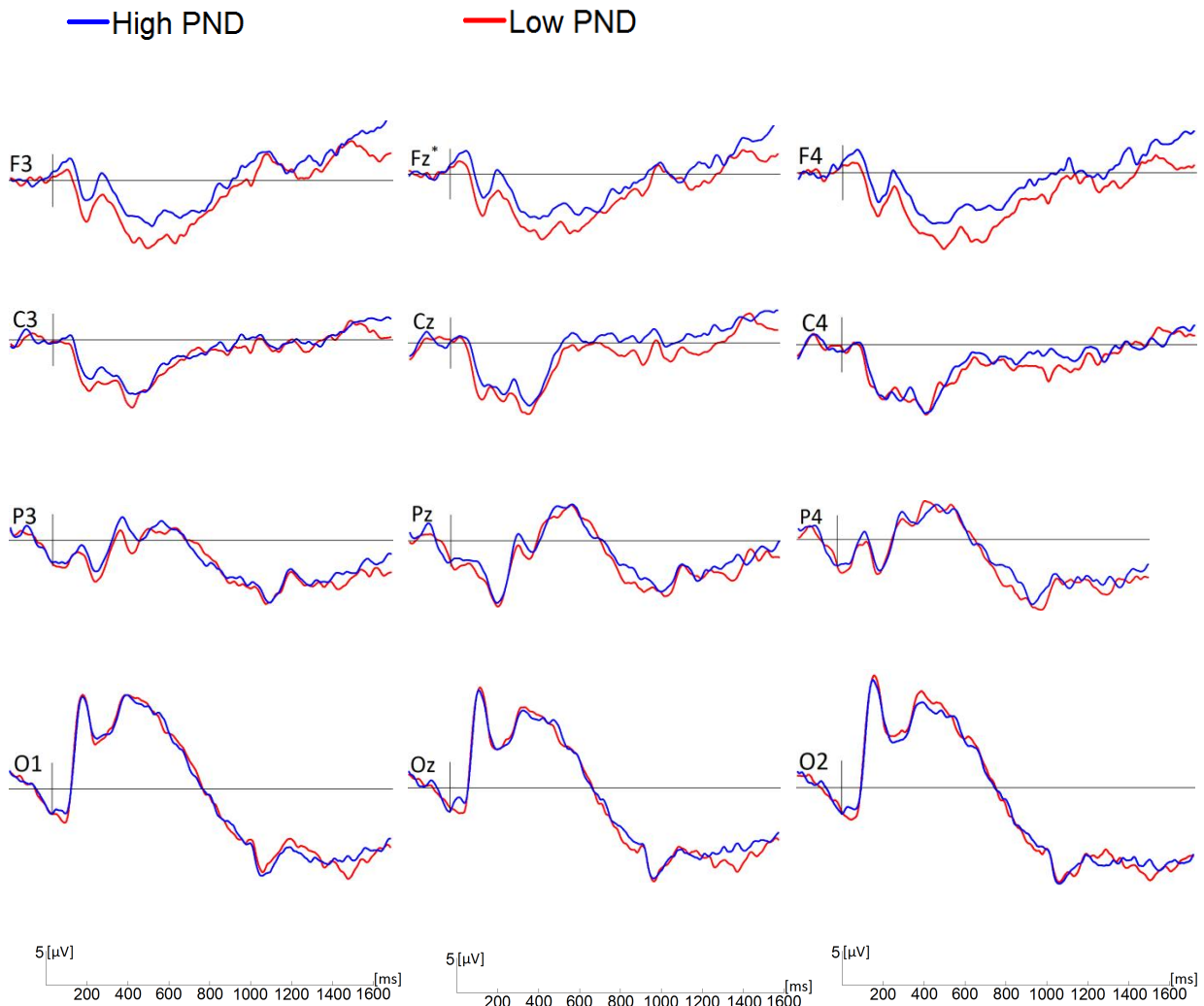


Figure 4.5. Grand averages of ERPs to pictures with different levels of Phonological Neighbourhood Density (PND) in 7-year-olds. High PND ERPs are represented by a blue line and low PND ERPs by a red line. To visualise the emergence of the PND effect anterior, central and posterior scalp locations are shown. The electrode site marked by an asterisk is shown in an extended view in Figure 4.6. Positivity is plotted upwards.

Early time windows (P1: 0–140 ms and N1: 120–250 ms):

For the early time windows the ANOVAs showed significant main effects for PND, which was strongest in the P1 range (P1: $F(1, 19)=8.74$, $p=.008$, $\eta^2=.15$; N1: $F(1, 19)=4.81$, $p=.041$, $\eta^2=.07$). Amplitudes of P1 to high PND words were more positive than those to low PND words. Amplitudes of N1 to high PND words were less negative than amplitudes to low PND words. Table 4.5 summarises the mean peak amplitudes of P1 and N1 for both experimental conditions at all three electrode sites. Significant main effects were also found for Electrode site (P1: $F(1.39, 26.53)=7.85$, $p=.001$; N1: $F(1.23, 23.29)=17.56$, $p<.001$). There was no significant interaction between PND and Electrode site (P1: $F(1.55, 29.44)=.73$, $p=.460$; N1: $F(2, 38)=1.09$, $p=.345$).

Table 4.5. Mean peak amplitudes (in μV) of P1 and N1 for each experimental condition at midline electrodes, along with standard deviations.

	High PND <i>M (SD)</i>	Low PND <i>M (SD)</i>
<i>P1 amplitude</i>		
Fz	7.36 (4.05)	3.88 (3.85)
Cz	3.85 (4.78)	2.12 (4.87)
Pz	1.58 (6.68)	-.85 (5.31)
<i>N1 amplitude</i>		
Fz	-6.58 (5.58)	-9.65 (5.55)
Cz	-11.99 (4.48)	-15.02 (5.46)
Pz	-15.16 (7.55)	-15.57 (6.67)

Note. PND = phonological neighbourhood density.

Later time windows (P2: 180–380 ms, N2: 300–490 ms and P3: 490–800 ms):

For the P2 and P3 time windows the ANOVAs showed a significant main effect of PND, which was strongest in the P2 range (P2: $F(1, 19)=9.02$, $p=.007$, $\eta^2=.13$; P3: $F(1, 19)=5.11$, $p=.036$, $\eta^2=.03$). The effect for N2 was not found to be significant, $F(1, 19)=2.77$, $p=.113$, $\eta^2=.03$. ERPs to high PND words were more positive than ERPs to low PND words. Mean peak amplitudes of P2 and P3 for both experimental conditions are summarised in Table 4.6.

Table 4.6. Mean peak amplitudes (in μV) of P2 and P3 for each experimental condition at midline electrodes, along with standard deviations.

	High PND <i>M (SD)</i>	Low PND <i>M (SD)</i>
<i>P2 amplitude</i>		
Fz	2.86 (4.45)	-1.05 (6.71)
Cz	-4.50 (4.72)	-6.74 (6.74)
Pz	4.17 (6.57)	1.56 (7.52)
<i>P3 amplitude</i>		
Fz	.06 (8.12)	-3.79 (9.58)
Cz	6.23 (8.06)	4.54 (6.59)
Pz	11.93 (7.66)	10.93 (7.66)

Note. PND = phonological neighbourhood density.

The main effect of Electrode site was significant in all three time windows (P2: $F(1.50, 28.52)=14.89$, $p<.001$; N2: $F(1.34, 25.38)=14.12$, $p<.001$; P3: $F(1.49, 28.25)=46.52$, $p<.001$). None of the ANOVAs conducted showed a significant interaction between PND and Electrode site (P2: $F(2, 38)=.45$, $p=.640$; N2: $F(1.51, 28.75)=1.29$, $p=.281$; P3: $F(1.49, 28.44)=.67$, $p=.478$). Figure 4.6 displays the grand average waveforms for electrode site of Fz. A topographic map of the ERP response as it unfolds following picture onset is further presented in Figure 4.7.

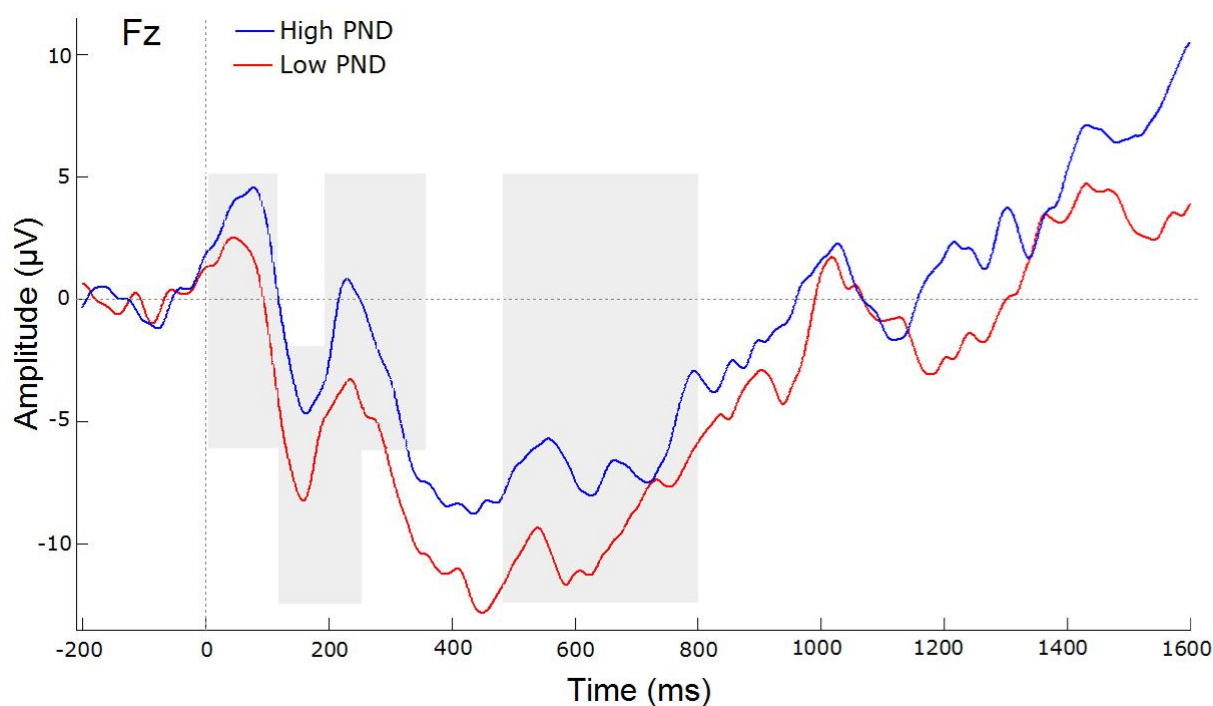


Figure 4.6. Grand average waveforms for electrode site Fz for pictures of high and low Phonological Neighbourhood Density (PND). High PND is represented by a blue line and low PND by a red line. Time windows significantly affected by PND level are indicated, 0–140 ms (P1), 120–250 ms (N1), 180–380 ms (P2) and 490–800 ms (P3).

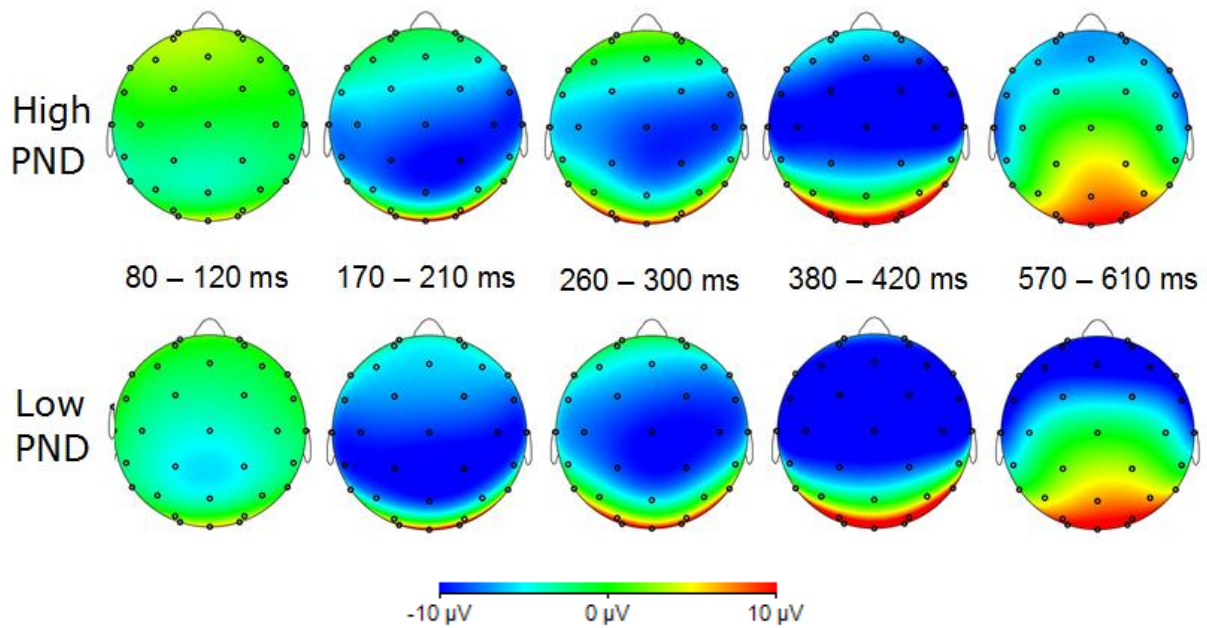


Figure 4.7. Topographic map of ERP response to pictures with different levels of Phonological Neighbourhood Density (PND), as it unfolds following picture onset.

Correlation Analyses

No significant ($p > .05$) Pearson's product-moment correlations between the individual mean peak latencies of low PND (Pz: $r = .28$; Cz: $r = .27$; Fz: $r = .12$) or high PND (Pz: $r = -.17$; Cz: $r = -.06$; Fz: $r = -.19$) with the corresponding individual mean RTs were present.

4.3.3 Discussion Experiment 2

In the present experiment ERPs and behavioural data were measured while healthy, English-speaking, school-age children overtly named pictures varying in PND. The aim was to test the feasibility of the methods and procedure in younger people and to gain first insights into the effect of PND on phonological processing in children.

Based on the findings from Experiment 1, where a PND effect was found at P3, with high PND evoking lower amplitudes compared with low PND, it was predicted that children would produce lower P3 peaks for high PND words than for low PND words.

Behavioural data showed no effect of PND. Seven-year-old children produced both types of pictures with similar accuracy and latency, replicating earlier behavioural studies that observed no effect of PND on reaction times in children (Bernstein Ratner et al., 2009). Despite the behavioural null results, electrophysiological data did reveal differences depending on the density level.

The peaks of the ERP waveforms appeared in the following time scale: P1 at around 90 ms, N1 at around 190 ms, P2 at around 280 ms, N2 at around 400 ms, and P3 at around 590 ms. These peaks appeared in a later time range compared with the ones observed for adults (Experiment 1), which is in line with past research reporting longer peak latencies in children than in adults (Budd et al., 2015; Laganaro et al., 2015). Grand averages further exhibited prominent negative waves, an

effect that has been observed in children across different experimental tasks, including pictorial stimuli (e.g., Greenham & Stelmack, 2001; Laganaro et al., 2015).

ERPs to high PND words started to diverge from the ERPs to low PND words within the P1 range and kept diverging until articulation onset. Significant amplitude differences between high and low PND were restricted to P1, N1, P2 and P3, with P1 and P2 showing the strongest effect of PND. Overall, ERPs to high PND words were more positive than ERPs to low PND words. While an influence of PND on the later P3 was expected, the finding of an early PND effect was surprising. In the following section, the theoretical implications of these results will be discussed. The early amplitude modulations will be considered first, since prelinguistic processing demands may explain the later effects observed at P2 and P3.

In the present experiment PND significantly modulated the P1 and N1 amplitudes. Based on the estimated time course of overt picture naming of school-age children provided by Laganaro et al. (2015) the P1–N1 complex corresponds to perceptual and conceptual operations (0–290 ms postpicture onset). The early effect of PND therefore points to processing differences extending language-related mechanisms.

Past ERP research has shown that the amplitudes of the visual P1 and N1 are modulated by the amount of spatial and object attention (for reviews see Herrmann & Knight, 2001; Hillyard & Anillo-Vento, 1998; Hopfinger & West, 2006). The amplitudes of P1 and N1 are greater for

stimuli features in attended (vs. unattended) locations and on attended (vs. unattended) objects (e.g., Anllo-Vento & Hillyard, 1996; Martínez et al., 2006; Martínez, Ramanathan, Foxe, Javitt, & Hillyard, 2007). Based on these findings, the observed early effect might reflect attentional differences regarding the visual input. Both experimental conditions invariably required attention to a single, presented picture at the same location. However, the material included a few coloured nonstandardised pictures for both PND conditions that were not tested for name agreement, which could have provoked modulations in the P1–N1 complex. Support for this assumption comes from past ERP research (Cheng et al., 2010). Cheng et al. examined the effect of name agreement in picture naming in adults. Name agreement refers to the extent to which different people agree on a name for a particular picture. One main source of name disagreement for pictures representing low name agreement was due to the uncertainty of the depicted object. Cheng et al. found an early effect of name agreement, starting at P1, with amplitudes for high-name-agreement (HNA) pictures evoking a larger positivity than those for low-name-agreement (LNA) pictures. They argued that “the P1/N1 results may reflect deployment of more attention to LNA than HNA pictures [since] some LNA pictures were of uncertain identity, and hence might require immediate attentional resources for identification” (Cheng et al., 2010, p. 138). Given these findings, the present results may represent differences in the attentional demand due to the ambiguity of

nonstandardised pictures, which may also exert influence on subsequent language-related processes.

In the current experiment P2 was significantly modulated. Past ERP research using picture naming in adults has associated P2 with lexical–semantic processing (e.g., Laganaro et al., 2012; Strijkers et al., 2010). The present P2 obtained from children peaked at around 280 ms postpicture onset, which is the very beginning of the lexical–semantic stage (about 290–480 ms), following the chronometry provided for school-age children (Laganaro et al., 2015). Amplitude differences may point to different processing efforts during lexical–semantic processing. Given the fact that pictorial attributes may be a confounder, ERP modulations might reflect the stressed lexical–semantic processing caused by picture ambiguity rather than by the effect of PND (Cheng et al., 2010). Picture ambiguity provokes the activation of more than one potential lemma, since alternative names are applicable. That is, in order to perform correctly, alternative responses have to be suppressed to prevent them from being selected. The current data showed that the ERP modulations were predominant at the frontal electrode sites (see Figure 4.5. Results section). The activation of prefrontal regions in children performing successfully during a task (i.e., performing inhibitory control) has been demonstrated in past brain imaging research (e.g., Moriguchi & Hiraki, 2013). The present observations would be in line with former studies showing that the selection from interfering semantic alternatives results in the activation of frontal brain regions, with greater activation

under conditions of greater competition (e.g., Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). Yet this is a tentative interpretation and there is no claim that the activity observed at the frontal electrodes reflects directly the neural source underneath it. Additional spatiotemporal research is needed.

The present data further showed a significant impact of PND at P3, which is in accordance with the original hypothesis predicting that P3 would be affected by PND. P3 peaked at around 590 ms after picture onset, falling within the time window of phonological processing (480–800 ms postpicture onset; Laganaro et al., 2015). No correlations between EMG-based reaction times and P3 peak latencies were found, further suggesting an effect at the premotor phase. Low PND words evoked a greater ERP response compared with high PND words (see Figure 4.5. Results section), indicating a greater processing effort for phonological sparse words. These findings can be explained within the model of interactive activation (Dell, 1986). Due to the fewer number of neighbours the target's phonological form will be less activated in comparison to words with dense neighbourhoods. The lower activation level presumably increases processing resources in order to access the required information (Prabhakaran et al., 2006). However, the electrophysiological data were not in accordance with the behavioural data, since naming latencies and accuracies did not show significant differences between both PND conditions. These findings indicate that neural processes underlying the P3 component did not directly influence articulation onset. That is, other

mechanisms than phonological processing might contribute to the observed P3 effect, such as attentional demand (Kok, 2001). Past ERP literature has reported that stimulus quality also affects the P3 amplitude. Findings show that “degradation of visual stimuli caused a reduction of P3 amplitude” (Kok, 2001, p. 565; Kok & Looren de Jong, 1980), implying that amplitude differences in P3 in the present experiment may be confounded by the nonstandardised picture material. Thus, even though an effect of PND was found at P3, it cannot be entirely ruled out that processing demands might be related to difficulties based on picture identification.

The current findings were based on a small number of trials and a small sample size, and can only be considered as the groundwork for future investigations. An increase in the number of trials along with controlled stimulus material could provide a more stable ERP pattern and more insights into the effect of PND on phonological processing on children.

In conclusion, this is the first study to observe effects of PND on ERPs in word production in children. Seven-year-olds showed ERP differences between high and low PND picture names, suggesting an impact of PND on underlying processes. However, ERPs to high PND words started to diverge from ERPs to low PND words within the early processing stages associated with prelinguistic operations (i.e., perceptual–conceptual processing), indicating differences in attentional demand due to the picture material. Although an effect of PND could be shown at P3,

with a greater ERP response to low PND than to high PND words, it cannot be entirely ruled out that amplitude differences might be confounded by the stimulus quality.

Interestingly, the observed electrophysiological differences between high and low PND words were not picked up by the behavioural measures. Production latencies and accuracies did not differ between the two PND conditions, not reflecting the preceding processing differences. The present ERP results expand the behavioural data, thereby substantiating the EEG/ERP approach in younger people.

4.4 General discussion of Experiments 1 and 2

The overall aim of the pilot studies was to test the feasibility of the experimental methods and procedure, thereby making a first attempt to examine the effect of PND during phonological processing of word production.

Past behavioural studies using picture-naming tasks reported modulations in naming latency and accuracy depending on PND level, indicating that underlying processes of word production are affected by PND. However, findings are contradictory, not allowing for a clear statement regarding the direction of the effect of PND, that is, whether or not phonologically dense words are facilitative during phonological processing (e.g., Sadat et al., 2014). Resolving this question is an essential step since PND has been identified as a potential predictor of

vocabulary development (Stokes, Bleses, et al., 2012; Stokes, Kern, et al., 2012; Stokes, 2010, 2014). Findings demonstrate that if the number of phonologically sparse words increases, so does the size of the expressive vocabulary. However, such a transitional development is not always present, as seen in late talkers, who retain a small vocabulary composed predominantly of phonologically denser words. These findings point to the theory that the processing of sparse words may require a different processing demand compared with dense words (Stokes, 2014). To reveal potential impairments in late-talking children, the closer investigation of the effect of PND on phonological processing in children with typical language systems is a precondition. As existing behavioural data is contradictory and limited to the overt outcome, capturing the processing demand in real time is more precise and informative. By making use of the techniques of EEG and ERP, the current experiments were able to detect changes in the strength of neural activation during the production of picture names varying in PND. As no EEG study exists that provides ERP data on the impact of PND on word production, the inclusion of adults was a necessary step before approaching children.

Based on former ERP research relating the N2 wave of stimulus-locked ERPs to phonological processing and the theoretical model of interactive activation during word production (Dell, 1986), it was predicted that high PND words would produce lower N2 peaks than low PND words.

Experiment 1 tested this hypothesis in healthy English-speaking adults. ERP results did not show an effect of PND at N2. But an effect could be revealed at about 400 ms postpicture onset, coinciding with the P3 wave, with high PND words evoking lower amplitudes than low PND words. These ERP modulations fall within a time window that has been associated with phonological encoding in previous literature (Indefrey, 2011). The lower P3 amplitude to high PND words suggests reduced processing demands during phonological encoding for phonologically dense words when compared with phonologically sparse words. Although the results did not entirely confirm the original hypothesis, since N2 was not affected, present findings still indicate differences in processing demands in favour of the hypothesis.

The ERP findings were in accordance with the observed behavioural data showing shorter production latencies for high PND than for low PND words, replicating similar observations in past research (Baus et al., 2008; Vitevitch, 2002). The accordance of electrophysiological and behavioural data indicates that PND affects neural processes that directly influence articulation onsets. The findings of Experiment 1 extend previous behavioural studies by revealing the sensitivity of neural structures to PND during the word production process and associated processing demands, validating the electrophysiological approach.

Based on the results of Experiment 1, Experiment 2 approached healthy 7-year-old children. Given that P3 and not N2 was significantly

modulated in Experiment 1, the hypothesis was that children would produce lower P3 peaks to high PND words than to low PND words.

ERP data showed significant differences of the P3 amplitude, with low PND words evoking a greater ERP response than high PND words. These results indicate a greater processing effort for phonologically sparse compared with phonologically dense words. However, significant amplitude modulations were also found for P1, N1 and P2. The early effect was unexpected, as the P1–N1 complex is associated with object recognition and concept processing (Laganaro et al., 2015). Given that the material included nonstandardised pictures, it was argued that the observed processing differences might represent the need of attentional resources induced by the pictorial rather than the linguistic properties.

Behavioural data did not differ significantly between high and low PND words, further indicating that the observed effect at P3 relates to neural processes that did not directly affect speech onset.

Taken together, the ERP findings from the pilot experiments suggest that words residing in dense phonological neighbourhoods are produced with less effort during phonological processing than words residing in sparse neighbourhoods. However, the results are preliminary and cannot be generalised since they may be confounded by the material used. The experiments were only based on a small number of trials. The smaller P3s could partly be due to a greater latency jitter registered for the P3 range. Further, although an effect of PND could be shown at P3 in Experiment 2

with children, it is possible that the differences in amplitude are confounded by the stimulus quality.

Compared to 7-year-olds, adults did not show ERP modulations during prelinguistic (P1 and N1) and lexical-semantic processes (P2). Taking the different sample sizes and associated influences into account, only a suggestive interpretation is made here about the potential reasons, aside from statistical ones, about the differential effect between children and adults. As recently reported by Laganaro et al. (2015), word production is prolonged in children, particularly because visual-conceptual stages as well as lexical-semantic and phonological processes are stretched out. The broader time window with the extended processing may amplify the effect caused by the picture material, making its impact visible at those stages. Furthermore, not only brain networks involved in language production but also control or inhibitory mechanisms have not yet fully developed to adult level (e.g., Dempster, 1992; Moriguchi & Hiraki, 2013). In word production semantically related words are the target's main competitors (Dell et al., 1997). Children showed a strong effect at P2, associated with lexical-semantic processing. Assuming that picture ambiguity may be a confounder, lemma selection might be more demanding in children than in adults, since the latter are more proficient or efficient in terms of inhibitory control, leading to a more constrained type of language processing (see also Jescheniak, Hahne, Hoffmann, & Wagner, 2006). As pointed out above, only assumptions can be made

here. The pilot experiments were not conducted to explicitly compare children and adults on their performance on the same task.

These pilot experiments have laid the initial groundwork with outcomes indicating neurophysiological changes depending on the phonological neighbourhood density, thereby showing results in favour of the hypothesis. That is, high PND evokes lower ERP amplitudes than low PND during a time window associated with phonological processing of word production.

Based on the findings of the pilot studies the main experiments were conducted. One goal of the main studies was to confirm the observed PND effect in children indicated in the pilot work. A second goal focussed on the effect of another lexical variable. The observation that neural structures are sensitive to phonological neighbours during phonological processing indicates the potential impact of coactivated neighbours during information retrieval. Past behavioural studies have shown that the semantic properties of a word also affect speech production (detailed in Chapter 5). The influence of semantic neighbours or semantic neighbourhood density during lexical-semantic processing was therefore another object of investigation. Semantic neighbourhood density refers to the semantic connectedness of words in the mental lexicon. The findings of Stokes (2014), who reported that the semantic information of low PND words is present in the lexicons of late-talking children, also pose the

question of how semantic neighbourhood density influences the word production process.

In the following chapter the effect of semantic factors on language production based on prior behavioural research will be surveyed, before turning to the implementation of the main experiments.

Chapter 5

Semantic factors on word production

5.1 Semantic factors in previous language production research

Past research has investigated semantic factors in word production mainly by manipulating the semantic contexts in which pictures were named, in order to reveal whether speech production is affected by the activation levels of semantically related words. The commonly used paradigms were the picture–word task and continuous or blocked naming. Findings from those studies are mainly based on adult data and will be summarised in the following sections.

In the picture–word paradigm participants are required to name pictures of common objects while ignoring embedded semantic distractor words. Findings from adults show that naming a picture (e.g., target *dog*) was slower when the distractor was from the same semantic category as the target (e.g., *cat*) compared with when it was unrelated (e.g., *car*; e.g., Damian & Bowers, 2003; Schriefers, Meyer, & Levelt, 1990). However, when distractors were more semantically similar to targets, such as describing associations with the target (e.g., *bone*) or parts of the target object (e.g., *tail*), participants named target pictures faster compared to unrelated distractors (Abdel Rahman & Melinger, 2007; Alario, Segui, & Ferrand, 2000; Costa, Alario, & Caramazza, 2005; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007; Sailor, Brooks, Bruening, Seiger-Gardner, & Guterman, 2009). Similar results were found when the

semantic distance within a category was manipulated (e.g., *wolf* as a semantically close distractor vs. *lizard* as a semantically far distractor, when *dog* is the target). Mahon et al. (2007) reported faster naming latencies as the within-category distance decreases between distractors and targets. Similar observations have been made in children. Slower response times were found when the distractor word was from the same semantic category as the target than when it was unrelated (Jerger, Martin, & Damian, 2002; children aged 5 to 7 years). But when pictures were paired with an associative distractor, naming was faster and more accurate in comparison with unrelated distractors (Brooks, Seiger-Gardner, & Sailor, 2014; children aged 6 to 11 years).

Other experimental studies avoided the influence of a distractor by using continuous or blocked naming paradigms. In a continuous naming task participants name pictures from various semantic categories (e.g., *cat*, ...*bus*, ...*table*, ...*duck*, ...*hammer*, ...*car*, ...*dog*). Findings from adults show that within-category items affect word production since corresponding naming latencies increased linearly (e.g., Belke, 2013; Navarrete, Mahon, & Caramazza, 2010). That is, the second animal in the sequence above (e.g., *duck*) was named more slowly than the first animal (e.g., *cat*), and the third animal (e.g., *dog*) was produced more slowly than the second animal.

In a blocked naming paradigm, participants name pictures belonging to two different types of blocks. In one type, all pictures come from the same semantic category, and in the other, all pictures come from different

semantic categories. Two main observations were made for blocked naming. When a block consisted of only a single presentation of a picture, that is, no repetition within the block, participants showed faster response latencies in semantically related than in unrelated blocks (Belke, Meyer, & Damian, 2005; Navarrete, Del Prato, Peressotti, & Mahon, 2014). However, when pictures were repeated multiple times within a block, participants named pictures in the related context more slowly than in the unrelated one (e.g., Abdel Rahman & Melinger, 2011; Damian, Vigliocco, & Levelt, 2001).

Taken together, findings from the aforementioned research indicate the potential influence of semantically related nontargets on speech production, since they affect naming latency or accuracy of the target word. However, although the context approach has made a great contribution to reveal the effect of semantically related words, results are inconsistent and still in debate regarding whether nontargets provide a facilitative or inhibitory effect during lexical-semantic processing. Moreover, the indirect approach of manipulating the semantic context rather than word-inherent semantic properties does not provide further insights into the impact of coactivated semantic neighbours (neighbourhood density). The potential effect of word-inherent attributes on word production has been considered only recently. Yet, to date only a scant amount of research exists (Mirman, 2011; Rabovsky, Schad, & Abdel Rahman, 2016), which will be surveyed more closely in the following section.

5.2 Effects of word-inherent semantic attributes

Recent behavioural research has started to provide evidence for the impact of word-inherent semantic properties on word production in adults. By comparing groups of stimuli that differed only in terms of semantic aspects but were otherwise matched on confounding variables, Rabovsky et al. (2016) and Mirman (2011) reported associated processing differences.

Rabovsky et al. (2016) manipulated in their picture-naming study the number of semantic features associated with a concept (e.g., *mouse*—is small, has four legs). That is, stimuli had either many semantic features or only few semantic features. Rabovsky et al. observed faster naming latencies and fewer errors for pictures with many semantic features compared with items with only a low number of semantic features. Mirman (2011) examined the effect of near and distant semantic neighbours during picture naming in aphasic patients and healthy adults. Near and distant neighbours were defined based on cosine distance between semantic feature vectors derived from McRae's semantic feature norms (McRae, Cree, Seidenberg, & McNorgan, 2005). Focusing on naming accuracy, Mirman reported that both participant groups made more errors when naming pictures with many near semantic neighbours relative to pictures with many distant semantic neighbours. Findings from these studies refine the semantic context effects discussed above by revealing the latent impact of word-inherent semantic attributes, which also shape word production. However, these studies further demonstrate

that a word's semantics can be captured through various measurements. While Rabovsky et al. (2016) made use of the number of semantic features, Mirman (2011) focussed on near and distant semantic neighbours. That is, both studies used different semantic parameters. In fact, no prevalent metric in the literature exists when it comes to measuring a word's semantic neighbour. While phonological neighbours are defined in terms of similarity over phonemes (Ph+/-1; Luce & Pisoni, 1998), the characteristics over which semantic neighbours should be determined are not as clear (Burgess & Lund, 1996; McRae et al., 2005; Nelson et al., 1998). Mainly three measurements exist that claim to capture the neighbourhood of semantic representations. Semantic neighbours can be defined either through their associative relatedness (e.g., *spider-web*; Nelson et al., 1998), their feature overlap (e.g., *duck-chicken*; McRae et al., 2005) or through their cooccurrence in written texts regardless of the properties shared by the objects (e.g., Burgess & Lund, 1996). Yet, there is little empirical evidence that any one of these measurements captures the nature of semantic representations in the mental lexicon (Mirman & Magnuson, 2008). Given this dividedness the following section will focus more closely on semantic neighbourhood density as it is used in this dissertation, and will also state the reason behind its use.

5.3 Semantic neighbourhood density

As reported in the prior section, language production research has used different parameters to define semantic properties, since no agreeing metric in terms of semantic neighbours exists. However, one measurement that has been commonly used in the context of word acquisition in young children (Hills, Maouene, Riordan, & Smith, 2010; Hills, Maouene, Maouene, Sheya, & Smith, 2009a,b; Hills, 2013; Storkel, 2009) is the property of semantic set size (Nelson et al., 1998), which has been declared by Storkel (2009) as “the semantic analog of [phonological] neighborhood density” (p. 301). This dissertation will therefore quantify semantic neighbourhood density (SND) by semantic set size.

Semantic set size refers to the number of words that are meaningfully related to (e.g., *dog-cat*) or frequently associated (e.g., *dog-friend*) with a given word (i.e., the number of semantic neighbours). Semantic set size is usually determined through a discrete association task (Nelson et al., 1998), in which a list of words is given to participants who report the first word that comes to mind for each. The responses are then summed to give a measure of the semantic set size of a word. Based on this approach the word *dog*, for example, provoked *cat*, *animal*, *puppy*, *friend* and *house* and thus has a set size or neighbourhood size of 5 (Nelson et al., 1998). Words with many semantic neighbours have a high SND and reside in dense neighbourhoods, whereas words with only a few neighbours have a low SND and reside in sparse neighbourhoods.

So far, the effect of semantic set size has been studied in the context of word recall in adults (e.g., Nelson, McKinney, Gee, & Janczura, 1998), lexical decision in adults (e.g., Buchanan, Westbury, & Burgess, 2001; Yates, Locker, & Simpson, 2003) and word acquisition in children (Hills, 2013; Hills et al. 2009a,b; Hills et al., 2010; Storkel & Adlof, 2009; Storkel, 2009). No research exists that investigated its influence on language production. The question still remains, therefore, whether semantic set size, or here SND, affects word production and whether an increase in semantic density is facilitative or inhibitory of information retrieval.

Chapter 6

Revealing the effects of phonological and semantic neighbourhood densities on underlying processes of word production in children

6.1 Introduction

Having laid the initial groundwork with the pilot studies, the second part of the dissertation aimed to confirm the observed PND effect in children, suggesting processing differences of names varying in PND during phonological encoding of the word form. At the same time, the main experiments conducted aimed to provide more insights into the effect of SND during word production in children.

The main purpose of the pilot phase was to test the feasibility of the methods and procedure in children, thereby making a first attempt to examine the impact of PND on phonological processing. Although findings of the pilot study with 7-year-olds suggested facilitative effects of high PND during phonological processing, as indicated by a reduced ERP response relative to low PND, these results are only preliminary. The findings were based on a small number of trials per condition, potentially affecting the stability of ERPs. In addition, the material used might have further confounded the ERPs with modulations potentially evoked by attentional differences due to picture quality. These limitations may not only have obscured the effect of PND but also the time at which PND comes into play during word production, since a robust effect has already been found in early processing stages associated with prelinguistic

operations in picture naming. Consequently, for the main experimental part the required adjustments were made, such as increasing the number of trials and ensuring the clarity of pictorial material, to underline the relative effect of PND in children.

Though preliminary, results of the pilot studies point to the sensitivity of neural structures to PND, thereby indicating the potential impact of coactivated neighbours during information retrieval. This gave rise to the consideration of the variable of SND. As discussed in Chapter 1, Stokes (2014) showed that phonologically sparse words are in the receptive lexicon of late-talking children but are scarce in their spoken output. These findings suggest that corresponding semantic representations are available. Investigating the impact of SND provides a better understanding of how semantic neighbours affect lexical-semantic processing during word production. Moreover, investigating SND together with PND gives more insight into similarities and differences between the effects of both densities in children, which can be relevant for clinical practice, especially with respect to children who are late talkers. Considering the effects of SND could help with the type of treatment manipulation, as words with different phonological densities may be processed differently, depending on the semantic density.

As discussed in Chapter 5, previous research has shown that the semantic relatedness of words affects speech production. Modulations in naming latencies and accuracies point to processing differences during the

word production process. Yet reported findings are not consistent, since semantically related words provide either a facilitative or an inhibitory effect on word processing. Importantly, the majority of the studies investigated the effect of semantic relatedness primarily through an indirect approach, by manipulating semantic contexts rather than word-inherent properties. The few studies that have examined the influence of word-inherent semantic attributes focussed on semantic parameters different from the one chosen in this dissertation. Here SND was quantified by semantic set size (Nelson et al., 1998) and, to the author's knowledge, no study exists that has addressed the influence of SND on behaviour or underlying processes of word production. That is, although findings from past research are promising, as they show that behavioural responses are modulated, they do not allow an inference regarding the relative effects of SND as it is defined in this dissertation.

In order to investigate the effect of PND on phonological processing and the effect of SND on lexical-semantic processing in children, two EEG/ERP studies were conducted (Experiment 3 and Experiment 4). Experiment 3 examined the effects of PND and SND in 7-year-old children during an overt picture-naming task while manipulating the material in terms of both variables. The corresponding findings gave rise to the consideration of an even younger age group (Experiment 4), which will be delineated in more detail in the discussion part of Experiment 3.

6.2 Experiment 3

Findings of the pilot study with 7-year-olds (Experiment 2) showed a significant effect of PND at P3, with low PND words evoking greater ERP responses than high PND words. These results suggest processing differences during phonological processing (Laganaro et al., 2015). However, significant amplitude modulations were also found for P1, N1 and P2. The early effects were unexpected, since the P1–N1 complex is associated with prelinguistic processes (Laganaro et al., 2015). These results point to processing differences related to pictorial properties rather than the linguistic manipulations. The material of the pilot study included some nonstandardised pictures, which were not tested for name agreement. As outlined in the discussion of Experiment 2 (see 4.3.3), name agreement has been found not only to affect the prelinguistic stages of picture naming but also lexical–semantic processing (Cheng et al., 2010). In addition, prior ERP literature has also stated the influence of stimulus quality on the P3 amplitude (e.g., Kok, 2001). Given these findings, the observed ERP modulations in Experiment 2 may be confounded by the nonstandardised picture material. Thus, one goal of the present experiment was to further examine the effect of PND on phonological processing in children. In order to reveal the relative effects of PND and to improve the neurophysiological outcome, methodical modifications were considered (see *Material* in the Methods part 6.2.1). In both pilot experiments an effect of PND was found at P3, with

phonologically dense words showing lower amplitudes than phonologically sparse words. The hypothesis was therefore:

Seven-year-old children produce lower P3 peaks to high PND words than to low PND words.

The corresponding research question was:

Is there a significant difference in mean amplitude of P3 in children between words of high PND and low PND?

A second goal of the present experiment was the investigation of the effect of SND during lexical-semantic processing of word production. The observation that neural structures are sensitive to phonological neighbours during phonological processing indicates the potential impact of coactivated neighbours on information retrieval and poses the question of the relative effects of SND. Existing research that has examined the influence of semantic relatedness on speech production only provides limited and inconsistent findings (see Chapter 5). So far, no study exists that has addressed the question of how SND influences the word production process in children. The current experiment took a lead in addressing this question.

Based on the theoretical framework of interactive activation of word production (Dell, 1986; see Section 2.4), where information retrieval depends on the target's activation level, dense neighbourhoods provide a facilitative effect. Past ERP studies examining the effect of linguistic variables during picture naming associated the temporal marker of

lexical-semantic processing with the P2 wave of stimulus-locked ERPs (see Section 3.2). Assuming that a reduced amplitude indicates a reduction in processing demands (see Section 3.1), the hypothesis was: Seven-year-old children produce lower P2 peaks to high SND words than to low SND words.

The corresponding research question was:

Is there a significant difference in mean amplitude of P2 in children between words of high SND and low SND?

6.2.1 Methods

Ethics approval

This project was approved by the University of Canterbury Human Ethics Committee (reference number HEC 2013/134). Children and their parents gave signed consent before completing the study.

Participants

Twenty one children aged between 7;0 and 7;11 participated in this study. None of the children took part in the prior PND pilot study. Participants were recruited from a database of volunteer families contacted via mail and through word of mouth. The data of two children were removed from the data set due to technical issues during the EEG recording. The mean age of the remaining 19 children was 7;5 with a standard deviation of 3 months. Six of these were females and all but one

participant were right-handed (defined by writing hand). All participants were required to meet the following inclusion criteria: (a) native, monolingual speakers of English; (b) were identified as typically developing; (c) no history of speech, language, or hearing impairment; (d) no serious (chronic) health problems (not taking medication); and (e) normal or corrected to normal vision. Parent report on a questionnaire was used to confirm that children met all of these conditions. The standardised *Receptive One-Word Picture Vocabulary Test* (ROWPVT-4; Brownell, 2011) was administered to all participants to ensure that all children performed within normal limits of their age regarding vocabulary knowledge. Word comprehension scores were within normal limits in all children (mean standard score = 114.53, $SD = 8.95$). Children received a small gift and a 10\$ voucher for their participation.

Material

Fifty-six coloured pictures corresponding to early acquired monosyllabic English words were selected from the colourized Snodgrass and Vanderwart picture set (Rossion & Pourtois, 2004) as well as from Google images that were not subject to copyright. Given that the nonstandardised pictures may have been a confounder in the pilot studies, a preliminary test with ten 7-year-old children who were not part of this study was carried out to ensure high name agreement of the pictures retrieved from Google images. Only pictures with 100% name agreement were used in the experiment. Picture names were manipulated in terms of

high and low phonological neighbourhood density as well as semantic neighbourhood density, making for the following conditions: high PND/high SND, high PND/low SND, low PND/high SND and low PND/low SND. Each experimental condition involved 14 pictures (see Appendix E for the stimuli list). To increase experimental power, number of trials was increased by presenting three separate blocks. Each picture was presented once within each block (i.e., 56 stimuli per block) and appeared in random order for every participant.

To identify phonological and semantic neighbours of each word the following databases were used: PND was retrieved from De Cara and Goswami's (2002) lexical database and SND from the University of South Florida Free Association Norms (Nelson et al., 1998). Both data bases use data from adults but were used here because no child corpora were available to provide such detailed measurements. Child and adult lexical databases have been reported to be positively correlated (e.g., Hills, 2013; Storkel & Hoover, 2010).

De Cara and Goswami's (2002) lexical database was used to retrieve phonological neighbours based on the +/- one phoneme metric. As mentioned above (see 4.2.1) this online database was chosen because of its British English. The median value served to equally separate words into low or high neighbourhood conditions ($Mdn=21,5$). The average PND for low density words was 12.71 ($SD=4.28$) and for high density words it was 32.64 ($SD=7.42$). The phonological neighbourhood sizes differed significantly from each other $t(54)=-12.30, p<.001$.

SND was defined through semantic set size (i.e., the number of different words that were generated by adults in response to a given word). The median value was used to equally separate words into low or high neighbourhood conditions ($Mdn=14$). The average SND for low density words was 8.54 ($SD=2.66$) and 18.89 ($SD=2.75$) for high density words. The semantic neighbourhood sizes differed significantly from each other $t(54)=-14.32, p<.001$.

Set matching

To evaluate the potential effects of PND and SND on speech production, stimuli were balanced on the following variables: word frequency, age of acquisition, imageability, index of phonetic complexity and phonotactic probability. These variables were reported as influential predictors of naming performance in previous studies on speech production (e.g., Alario et al., 2004; Vitevitch et al., 2004).

All of these variables were assessed using the same databases as described in the methods sections of the pilot studies (please see 4.2.1 for thorough descriptions of the databases). Word frequency was retrieved from De Cara and Goswami's (2002) lexical database. Age of acquisition norms were obtained from Cortese and Khanna (2008) and Imageability was taken from Cortese and Fugett (2004). For one included word no ratings of age of acquisition and imageability were available (mouse). Here the average age of acquisition value or imageability value of the other members of the corresponding experimental condition was used (for

the same approach see Middleton & Schwartz, 2011; Newman & German, 2002).

To identify the index of phonetic complexity for each word Jakielski's (2000) scoring protocol was used (see Appendix B). Each word was transcribed phonetically using the International Phonetic Alphabet (IPA: reference) and then scored according to the eight phonetic factors. Scoring was performed independently by the author and a speech and language pathologist to assure reliability ($r=.93$). The IPC scores for the word stimuli are listed in Appendix F.

Considering phonotactic probability the principle was applied that the varieties of English do not vary too much, taking account of the /r/ coloured vowels used in the USA English. The Phonotactic Probability Calculator by Vitevitch and Luce (2004) was used to calculate biphone frequency and positional segment frequency.

The differences in word frequency, age of acquisition, imageability and IPC were assessed using one-way ANOVA. There was no statistically significant difference between the four experimental conditions on word frequency ($F(3, 52)=.91, p=.44$), age of acquisition ($F(3, 52)=.51, p=.68$), imageability ($F(3, 52)=1.67, p=.19$) and index of phonetic complexity ($F(3, 52)=2.65, p=.06$). For phonotactic probability a nonparametric comparisons was used because of lack of homogeneity in the variance for the biphone frequency measures. The used Kruskal-Wallis test showed that there were no statistically significant differences among

the conditions for biphone frequency, $\chi^2(3)=5.87$, $p=.128$ or positional segment frequency, $\chi^2(3)=4.59$, $p=.204$.

Procedure

ERP experiment

Participants were tested individually in a soundproof room sitting approximately 1.10 m in front of a computer monitor, which was placed level with the participants' gaze. The experimental task was an overt picture-naming task. To familiarise participants with the experiment the task began with eight practice trials, followed by three experimental blocks each comprised of 56 trials. None of the practice stimuli were used as experimental stimuli and were excluded from further analysis. Participants performed accurately on these practice trials, indicating that they understood the task well enough to progress onto the experimental trials.

The presentation of the trials was controlled by the E-Prime software (E-Studio; version 2.0, Psychology Software Tools, Inc., Pittsburgh, PA). Each trial had the following structure: It began with the presentation of a black fixation cross shown at the centre of a white screen for 500 ms. Then the picture appeared in the middle of the screen, which was presented for 2000 ms. Picture stimuli were displayed in a constant size of 9*9 cm on a white background. Participants were instructed to overtly name the word corresponding to the picture as quickly and accurately as possible. A blank inter-trial-interval was jittered randomly from 2500 ms

to 3500 ms. Each picture was shown once within each experimental block presented randomised for every participant. Blocks were separated by small breaks during which children were asked to stretch, close their eyes or have a sip of water. The general duration of the breaks was about three minutes.

Participants received instruction on how to reduce eye blinks and muscle activity to avoid artefacts. Further, they were explicitly advised to say only the names of the stimuli and not to chat during the experimental trials. Misnomers of the stimuli were noted by the experimenter. The entire experiment lasted about 60 minutes including placement of the electro cap and short breaks between the blocks.

EEG acquisition and preprocessing

The EEG was recorded from 32 pin-type Ag-AgCl sintered Active-electrodes using a BioSemi Active Two amplifier system (Biosemi V.O.F. Amsterdam, Netherlands). Electrodes were placed in standard International 10–20 System locations. EEG was recorded with a Common Mode Sense (CMS) active electrode and a Driven Right Leg (DRL) passive electrode as reference and ground, respectively (<http://www.biosemi.com/faq/cms&drl.htm>). To register eye movements, individual electrodes were placed next to the left and right eye for horizontal eye movements and above and below the left eye for vertical eye movements. Two additional electrodes were placed on the participants' left and right ear lobes for off-line referencing. In order to

detect response activation two approaches were used measurement of the acoustic signal and measurement of the EMG (McArdle et al., 2009). The acoustic response signal was recorded by using a microphone which connected directly to the BioSemi ActiveTwo Ergo input on the AD-box and was mounted approximately 1 m in front of the participant. Two electrodes were used to measure the EMG. One was placed at the vermilion boarder of the upper lip and another one under the chin. Data were sampled at a rate of 1024 Hz with band-pass filters set between 0.16–268 Hz.

The BrainVision Analyzer software (Brain Products GmbH, München, Germany) was used to conduct the offline EEG analyses. The data were re-referenced to the averaged voltage of the two earlobe electrodes. The EEG was bandpass-filtered to 0.1 to 20 Hz (slope: 24 dB/octave) using also a notch filter (50 Hz). The signal was then segmented into 1800-ms-long epochs starting 200 ms prestimulus until 1600 ms poststimulus. Segments were baseline corrected using the EEG data from -200–0 ms relative to picture onset. An eye regression routine (Segalowitz, 1996) was used to remove eye movement artefacts. Segments with voltages exceeding $\pm 100\mu\text{V}$ on any of the investigated EEG channels or the bipolar EOG channels were removed. This artefact rejection process was applied from stimulus onset until 800 ms poststimulus in order to preserve segments for the individual average. The experiment was an overt naming task and motor artefacts, predominantly present at later time periods, would have caused segment reduction. Trials with incorrect or absent

responses were excluded. A criterion of $\geq 30\%$ correctly answered trials per condition after rejection of eye-blinks and artefacts were applied to construct a stable ERP. Averaged ERPs for high PND, low PND, high SND and low SND segments were calculated for each participant.

Data analysis

In order to complement the neurophysiological data, the behavioural data was also analysed.

Behavioural data

Word errors

Participants' responses were examined for speech errors. Three types of errors existed: autocorrection (0.9%), absence of reaction (1.3%) and giving an incorrect name (wrong response; 6.6%). Given the very low amount of autocorrections and the fact that absent reactions could have occurred due to reasons other than the linguistic factors, further statistical analysis only focused on the error type wrong responses. A 2 x 2 repeated measures ANOVA was conducted with PND (high and low) and SND (high and low) as variables.

Reaction time

Only behavioural data based on the acoustic response recorded through the microphone are reported here. Thus, reaction time (RT) refers to the acoustic onset.

The acoustic onsets were analysed using a Matlab routine (MATLAB and Statistics Toolbox Release 2013a, The MathWorks, Inc., Natick, Massachusetts, United States) which allowed for automatic scoring and visual inspection of the RT. RT was detected within a specified time window encompassing 800 ms prepicture onset and 3000 ms postpicture onset (Figure 6.1). RT was quantified on a trial by trial basis for each participant and defined as the first location where the μV value was more than 3.5 SD above the mean μV value in reference to the baseline (corrected time period starting 1100 ms prepicture onset and ending 100 ms before picture onset). All trials were reviewed by the author without knowing to which of the four conditions they belonged and which trial number they represented. Only trials where the intended target word was produced were considered. Trials with RTs shorter than 350 ms (0.1%) were excluded (e.g., Laganaro et al., 2015; Porcaro et al., 2015).

A 2 x 2 repeated measures ANOVA was carried out with PND (high and low) and SND (high and low) as variables. If this two-way ANOVA showed a significant interaction (with alpha set to .05), further analyses was conducted using Tukey's *a priori* *t*-test (Kirk, 1995).

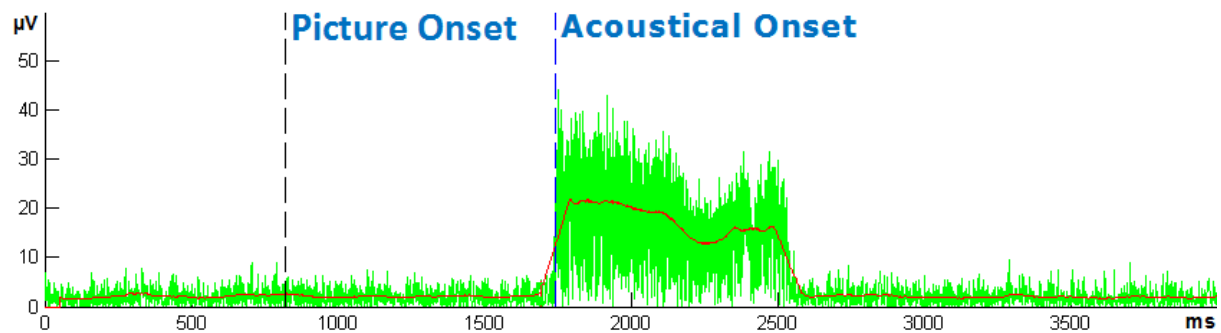


Figure 6.1. Identification of articulation onset using an acoustical signal.

ERP data

Nineteen participants reached the criterion of $\geq 30\%$ correctly answered trials per condition after rejection of eye-blinks and artefacts. Based on visual inspection of the grand average waveforms, five time windows containing visible peaks were selected: 0–140 ms (P1 peak), 120–250 ms (N1), 250–350 ms (P2), 320–480 ms (N2) and 450–800 ms (P3). The data were processed using a Matlab routine which allowed for automatic scoring and visual inspection of ERP peaks, and also allowed for manual scoring, when necessary (Gavin, 2014). Within each defined time window the Matlab routine automatically selected the maximum signal deviation from the baseline. Baseline-to-peak amplitudes and latencies for the P1, N1, P2, N2, and P3 were obtained from each averaged ERP waveform. All peaks were measured at the electrode sites of Pz, Cz and Fz. These electrode sites were chosen based on prior findings from the pilot experiments and past research reporting cognate effects over parietal and frontal sites (Christoffels et al., 2007; Strijkers et al., 2010). All ERP measurements were carried out by the author.

The statistical analysis was as follows. In each time window, mean amplitudes were compared using a 2 x 2 x 3 repeated measures ANOVA with PND (high and low), SND (high and low) and Electrode site (Pz, Cz and Fz) as variables. Mauchly's test was used to evaluate the assumption of sphericity and if the test was significant, the Greenhouse–Geisser adjustment was applied. If the three-way ANOVA showed significant interactions involving PND or SND (with alpha set to .05), further analyses were conducted using Tukey's *a priori t*-test (Kirk, 1995).

6.2.2 Results

Behavioural data

Word errors

Table 6.1 displays the means of two word error types for each condition: wrong response and absent reaction. The conducted ANOVA for wrong responses showed no significant main effect of PND ($F(1, 18)=.36$, $p=.554$) and SND ($F(1, 18)=.37$, $p=.550$), nor an interaction between both ($F(1, 18)=3.92$, $p=.063$).

Table 6.1. Mean and standard deviations of word errors for each experimental condition in 7-year-olds.

	Word Errors	
	Wrong Response	Absent Reaction
	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)
<i>Low PND</i>		
Low SND	3.16 (1.74)	.68 (1.11)
High SND	2.16 (1.89)	.63 (.89)
<i>High PND</i>		
Low SND	2.11 (1.76)	.47 (.96)
High SND	3.68 (3.42)	.53 (.91)

Note. PND = phonological neighbourhood density; SND = semantic neighbourhood density.

Reaction time

The mean reaction times for each experimental condition are shown in Table 6.2. The conducted ANOVA revealed a significant main effect of PND, $F(1, 18)=18.98$, $p<.001$, $\eta^2=.06$. Participants produced pictures with high PND names faster than pictures with low PND names. No significant main effect of SND existed ($F(1, 18)=1.67$, $p=.213$). The interaction between PND and SND was significant, $F(1, 18)=7.64$, $p=.013$, $\eta^2=.01$. The effect of SND was larger for low PND (39.41 ms) than for high PND words (1.07 ms), with high SND yielding significantly faster

reaction times than low SND in the low PND condition, $t(111)=5.38$, $p<.001$.

Table 6.2. Mean and standard deviations of articulation onsets in ms for each experimental condition in 7-year-olds.

	<i>M</i>	<i>SD</i>
<i>Low PND</i>		
Low SND	1005.29	119.37
High SND	965.88	106.61
<i>High PND</i>		
Low SND	936.55	111.81
High SND	937.62	94.50

Note. PND = phonological neighbourhood density; SND = semantic neighbourhood density.

ERP data

Figure 6.2 shows the general structure of the ERP pattern that was characterised by prominent negativities. The effects of PND and SND appeared most pronounced at about 400 ms postpicture onset. Further exploration of the data confirmed these observations. The electrode site marked by an asterisk is shown in an extended view in Figure 6.4.

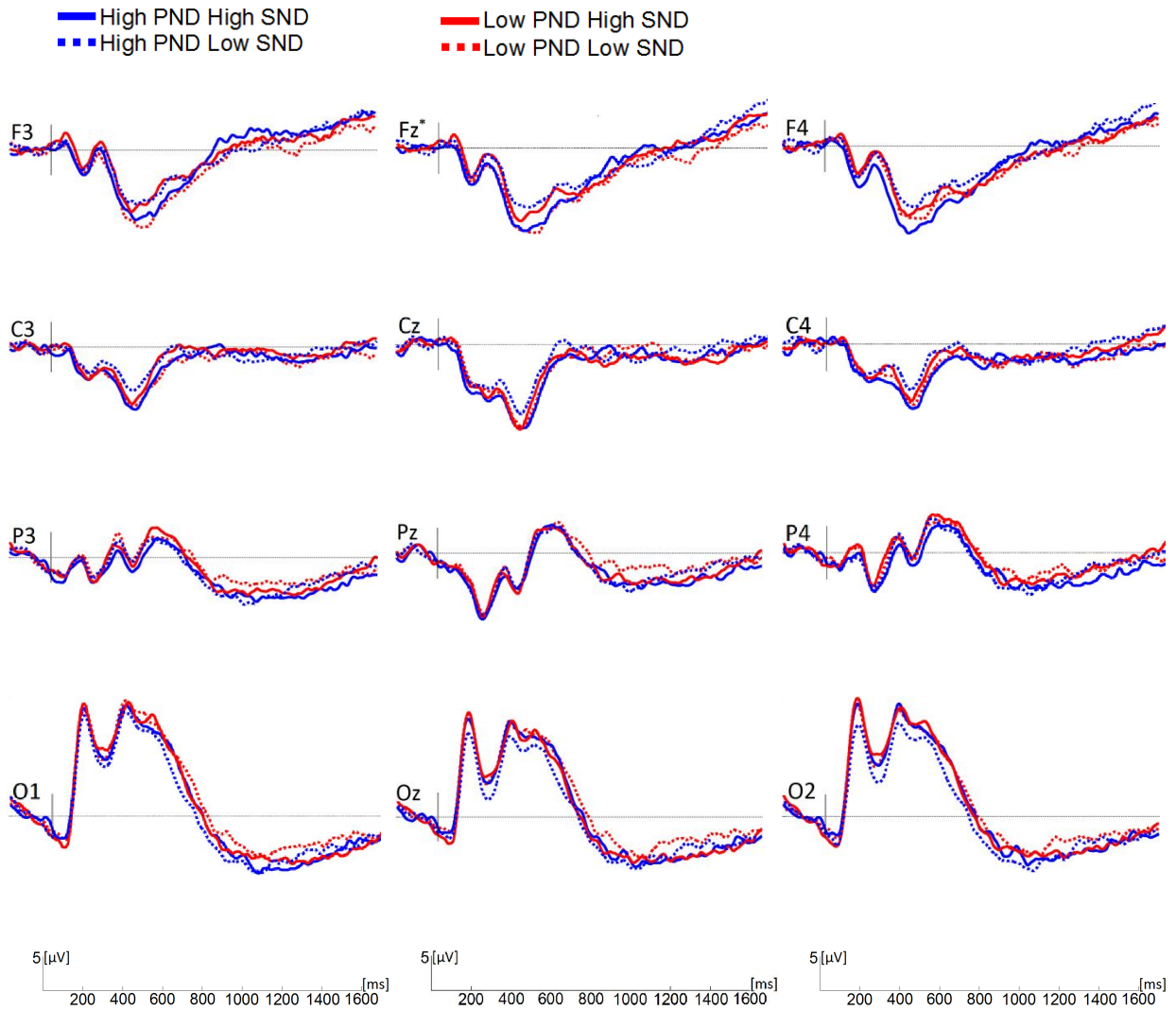


Figure 6.2. Grand averages of ERPs to pictures with different levels of Phonological Neighbourhood Density (PND) and Semantic Neighbourhood Density (SND) in 7-year-olds. To visualise the emergence of the PND and SND effects anterior, central and posterior scalp locations are shown. Positivity is plotted upwards. The electrode site marked by an asterisk is shown in an extended view in Figure 6.4.

Early time windows (P1: 0–140 ms and N1: 120–250 ms):

The only significant main effect found in the early time windows was for Electrode site (P1: $F(2, 36)=4.73$, $p=.015$; N1: $F(2, 36)=30.21$, $p<.001$). There was neither a main effect of PND (P1: $F(1, 18)=.62$,

$p=.443$; N1: $F(1, 18)=.94$, $p=.346$) nor a main effect of SND (P1: $F(1, 18)=1.03$, $p=.325$; N1: $F(1, 18)=2.34$, $p=.143$). None of the ANOVAs showed significant interactions (PND x SND: P1: $F(1, 18)=1.36$, $p=.259$; N1: $F(1, 18)=3.21$, $p=.090$; PND x Electrode site: P1: $F(2, 36)=.13$, $p=.879$; N1: $F(2, 36)=.13$, $p=.875$; SND x Electrode site: P1: $F(2, 36)=2.15$, $p=.131$; N1: $F(1.52, 27.32)=2.06$, $p=.156$; PND x SND x Electrode site: P1: $F(2, 36)=.70$, $p=.503$; N1: $F(1.37, 24.58)=.59$, $p=.502$).

Later time windows (P2: 250–350 ms, N2: 320–480 ms and P3: 450–800 ms):

Main effects were only present for Electrode site (P2: $F(2, 36)=16.96$, $p<.001$; N2: $F(1.34, 24.13)=20.53$, $p<.001$; P3: $F(2, 36)=43.97$, $p<.001$). None of the ANOVAs conducted showed significant main effects of PND (P2: $F(1, 18)=.14$, $p=.715$; N2: $F(1, 18)=2.83$, $p=.110$; P3: $F(1, 18)=.83$, $p=.375$) or SND (P2: $F(1, 18)=.55$, $p=.467$; N2: $F(1, 18)=2.41$, $p=.138$; P3: $F(1, 18)=.43$, $p=.521$). A significant interaction between PND and SND was revealed in the N2 time window, $F(1, 18)=7.43$, $p=.014$, $\eta^2=.04$ (P2: $F(1, 18)=1.48$, $p=.240$; P3: $F(1, 18)=.87$, $p=.362$). The effect of SND varied depending on the PND level (see Figure 6.3). A significant three-way interaction, PND x SND x Electrode site, in the N2 time window was also found, $F(1.26, 22.72)=4.92$, $p=.030$, $\eta^2=.01$ (P2: $F(2, 36)=2.04$, $p=.144$; P3: $F(2,$

36)=.919, $p=.408$). Further analyses revealed that the crossover interaction was confined to the frontal electrode site. ERPs to high SND (-16.69 μV) were less negative than to low SND (-19.41 μV) in the low PND condition, $t(198)=-2.89$, $p<.005$, while it was reverse in the high PND condition. Here, ERPs to low SND (-14.55 μV) were less negative than to high SND (-18.98 μV), $t(168)=-4.73$, $p<.001$ (see Figure 6.4).

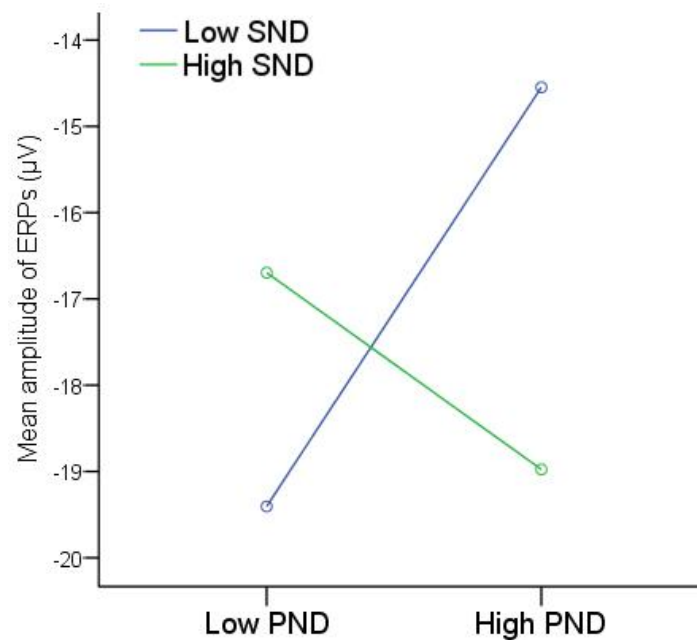


Figure 6.3. The interaction between Phonological Neighbourhood Density (PND) and Semantic Neighbourhood Density (SND) in N2 at the electrode site of Fz. Amplitude differences between low SND and high SND were larger in the high PND than in the low PND condition.

No other significant interactions were found (PND x Electrode site: P2: $F(2, 36)=.25$, $p=.782$; N2: $F(1.53, 27.57)=.14$, $p=.818$; P3: $F(1.44, 25.99)=1.99$, $p=.165$; SND x Electrode site: P2: $F(2, 36)=.62$, $p=.543$; N2: $F(2, 36)=.88$, $p=.426$; P3: $F(2, 36)=1.86$, $p=.171$).

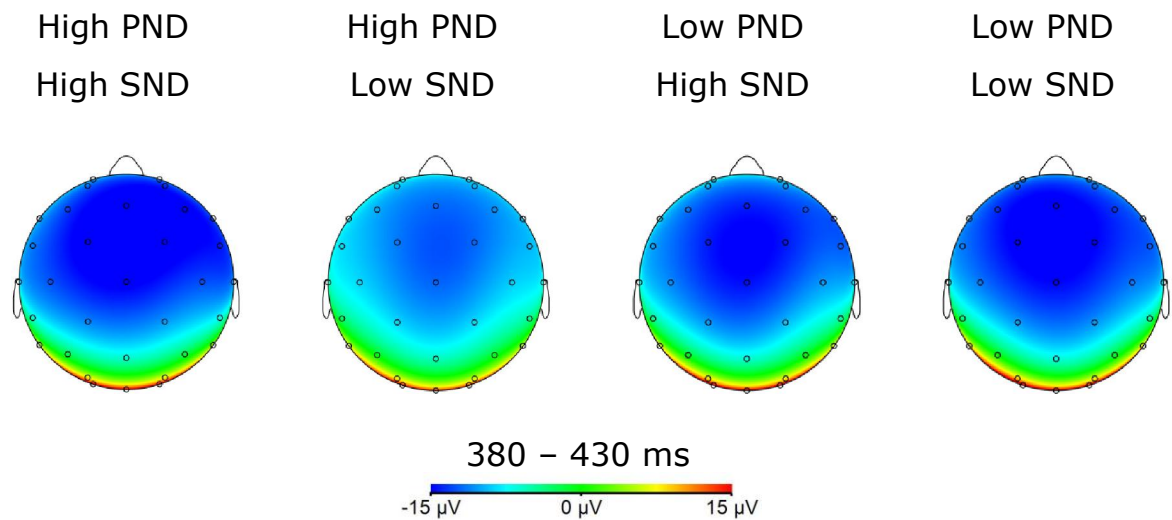
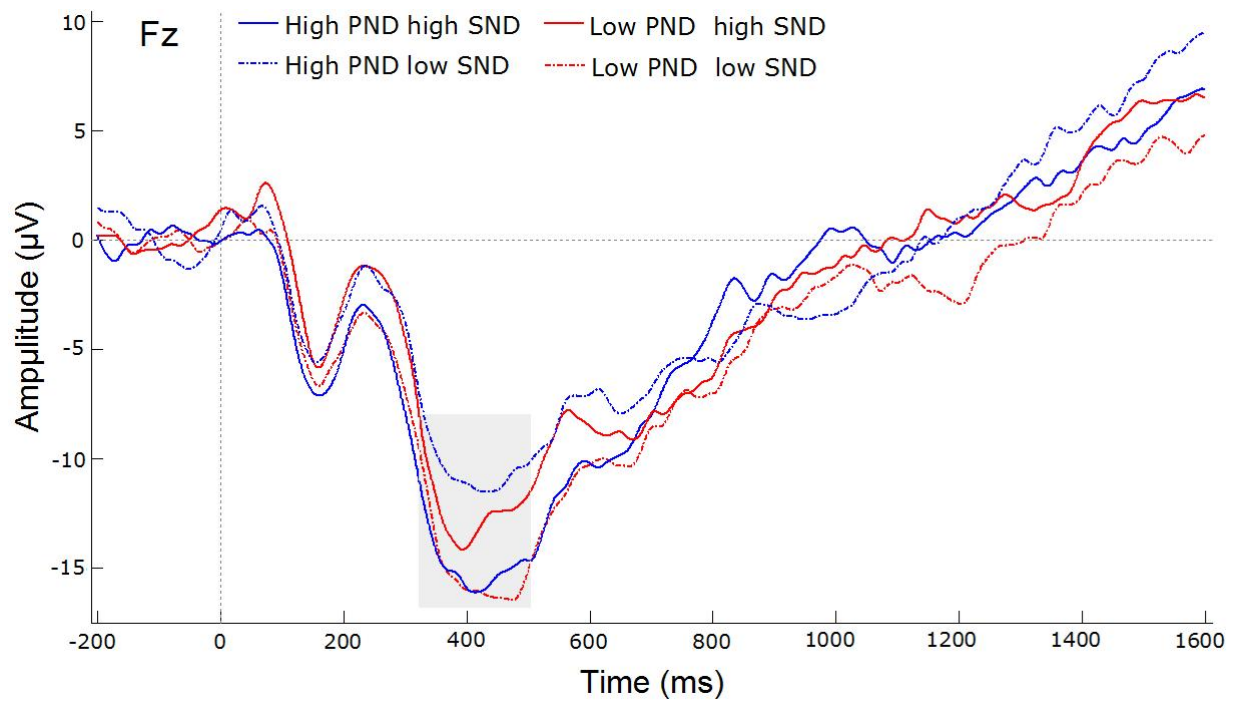


Figure 6.4. N2 event-related potential results. Grand averages of ERPs to pictures with different levels of Phonological Neighbourhood Density (PND) and Semantic Neighbourhood Density (SND) at Fz. The time window (N2: 320–480 ms) significantly affected by an interaction is indicated. Below is the topographic distribution of this effect in the time range of 380 to 430 ms postpicture onset.

6.2.3 Discussion Experiment 3

In the present experiment ERPs and behavioural data were measured while healthy, English-speaking, 7-year-old children overtly named pictures representing different levels of PND and SND. One goal of this study was to examine the impact of PND during word production in children, to further reveal the relative effects of PND on phonological processing. Based on the findings from the pilot studies, where a PND effect was found at P3, with high PND evoking lower amplitudes compared with low PND, it was predicted that 7-year-olds produce lower P3 peaks to high PND words than to low PND words. A second goal focussed on the effect of SND during lexical-semantic processing. Based on previous ERP research that associated lexical-semantic processing with P2, and based on the theoretical framework of interactive activation (Dell, 1986), it was predicted that children produce lower P2 peaks to high SND words than to low SND words.

Overall, 7-year-old children named high PND pictures significantly faster than low PND pictures, thereby replicating findings from Experiment 1 of this dissertation and earlier studies that reported faster naming for high PND relative to low PND (Baus et al., 2008; Vitevitch, 2002). While PND had a robust impact on reaction time, SND showed no main effect. However, a small interaction effect between SND and PND existed. Depending on the PND level, high SND provided a facilitative effect. This was only true for the low PND condition. Pictures low in PND but high in

SND were produced significantly faster than those with low PND and low SND. In the high PND condition SND showed no influence. Here reaction times were almost identical. Electrophysiological data further supported the interaction between PND and SND.

The peaks of the ERP waveforms appeared in the following time scale: P1 at around 90 ms, N1 at around 190 ms, P2 at around 280 ms, N2 at around 400 ms, and P3 at around 620 ms. The peaks appeared in a similar time range as that reported in the pilot experiment with children. Again, prominent negative waves were observed that have been described in past ERP research (e.g., Greenham & Stelmack, 2001; Laganaro et al., 2015).

The ERP data did not show unique effects of PND and SND. The results, therefore, did not confirm the original hypotheses that predicted amplitude differences between high and low PND at P3, and between high and low SND at P2, respectively. Instead, results showed that both variables significantly modulated the amplitude in the N2 range through an interaction effect predominant at the frontal electrode site. Depending on the PND condition, the effect of SND varied. Within the low PND condition, high SND showed lower negativities than low SND. For the high PND condition the reverse was found. Here high SND evoked larger negativities than low SND. The lower amplitudes to low PND/high SND words compared with low PND/low SND ones indicate processing differences in favour of the hypotheses, with dense neighbourhoods facilitating the processing (Dell, 1986). However, the greater amplitudes

to high PND/high SND words relative to high PND/low SND items do not conform to this assumption. A tentative explanation for the interaction effect and the theoretical implications will be discussed in the following sections.

The N2 peaked at around 400 ms postpicture onset, a time period that has been associated with lexical-semantic processing (about 290–480 ms) in school-age children (Laganaro et al., 2015). The time course provided by Laganaro et al. refers to an average naming latency of 1146 ms. The mean production latency observed in the present experiment was shorter (961 ms). Thus, underlying processes may have shifted slightly, suggesting an engagement of phonological processing by that time. Support for this assumption comes from prior ERP research that examined the effect of morphologically complex words on underlying processes in 8- to 12-year-old children and adults (Budd et al., 2013). Participants had to produce regular and irregular past-tense forms of English verbs (e.g., *walked* vs. *fell*). Budd et al. reported electrophysiological differences between 300 and 550 ms poststimulus onset, with regular past-tense inflection eliciting a more negative waveform than irregular past-tense forms. The authors argued that the obtained effect was unlikely to reflect lexical-semantic processing but rather phonological encoding. Further support for the assumption of phonological processing comes from prior ERP research in adults that associated the N2 wave evoked during picture naming with phonological encoding (e.g., Christoffels et al., 2007; Strijkers et al., 2010). A commencement of phonological processes in the

current experiment is therefore likely. It is suggested that the observed interaction effect between PND and SND at N2 arises during phonological processing.

In the framework of interactive spreading activation (Dell, 1986), low PND words have lower levels of activation during word-form retrieval relative to high PND ones, due to the smaller number of contributing neighbours. As a consequence, greater processing demands may be required to ultimately access a target's phonological representation, presumably resulting in increased neural activation. The need for greater processing effort is supported by the behavioural data in the present experiment, showing significantly longer naming latencies for low than for high PND. However, the activation level of low PND words may increase when the word resides in a dense semantic neighbourhood. Assuming that the phonological level is minimally activated for low PND words, the enhanced activation from the semantic level may help to identify or select the correct phonological form (for a similar account of the SND effect in lexical decision, see Yates et al., 2003). The attenuated amplitude observed for low PND/high SND words may reflect the lower demand in information retrieval during phonological processing. In contrast, during the processing of low PND/low SND words the system is minimally activated. The overall lower activation level may increase the effort, in order to ultimately select and retrieve the target's phonological information, as seen in the larger amplitude. The need for greater processing demands is additionally supported by the corresponding

behavioural data that show longer naming latencies for low PND/low SND words compared with low PND/high SND ones. The faster response to the latter word type supports the assumption of the facilitated and accelerated word-form retrieval.

In contrast to low PND words, high PND ones have higher levels of activation during phonological processing, with a denser neighbourhood contributing to the target's phoneme retrieval (Dell, 1986). As a consequence, subsequent processes associated with articulatory preparation are initiated earlier, resulting in faster articulation onsets, as seen in the current data. Unlike in the low PND condition, SND did not affect the naming latency in the high PND condition. Yet the corresponding electrophysiological data showed an effect of SND, with high SND evoking larger ERP amplitudes than low SND. That is, ERP and behavioural data are not in accordance for the high PND condition.

The findings that PND had a main effect on reaction time and that high PND was responsible for the reduction in naming latency, may point to the fact that other mechanisms, which did not directly influence articulation, contribute to the observed effect at N2. The convergence of both densities, semantic and phonology, at the phonological level might induce an increased demand on control processes. In a former study conducted by Jescheniak et al. (2006) the potential impact of coactivated lemmas on the phonological level was investigated in 7- to 10-year-old children and adults. Participants had to name pictures of objects while ignoring auditory distractor words that were phonologically related to

semantic associates of the target (e.g., *doll*, related to *dog*, if *cat* is the target). Jescheniak et al. (2006) found the distractor effect to be strongest in the youngest group, as naming latencies decreased substantially with age. They localized the effect at the phonological level, where coactivated phonological representations of semantic associates induced interference. Jescheniak et al. argued that due to immature inhibitory mechanisms, children were not as proficient as adults at suppressing irrelevant information, affecting word-form retrieval. In a recent ERP study, Shao, Roelofs, Acheson, and Meyer (2014) investigated whether inhibitory control would also be involved in word production when there is no overt distractor. Using a picture-naming task in adults while manipulating the variable of name agreement, they observed differences in the N2 amplitude (170–330 ms postpicture onset) at the frontal site. Relative to high name agreement, low name agreement showed larger amplitudes, and was associated with a stronger recruitment of selective inhibition. Based on these findings, it might be that the enlarged negativity to high PND/high SND names partially reflects inhibitory control. In the high PND/high SND condition, the processing system is maximally activated. The larger number of coactivated semantic neighbours and the increased phonological overlap of the target with other words lead to a larger number of activated phonological representations (i.e., phonological representations of coactivated lemmas and the phonological neighbours). This may increase the demand of control processes, in order to direct information retrieval. Under this context,

children would undergo a higher cognitive cost during the high PND/high SND condition relative to the high PND/low SND one, since the coactivation is reduced for the latter condition. Even so, this is a tentative proposal and further research is required. Interestingly, however, the increased processing demand induced by high SND did not impede articulatory preparation, as both conditions—high PND/high SND and high PND/low SND—yielded identical naming latencies. These findings point to a strong and facilitative effect of high PND on processes that directly influence articulation. In comparison, electrophysiological and behavioural data were in accordance for the low PND condition. Even though reaction times were decisively affected by low PND, high SND appears to accelerate articulation onset, presumably due to its facilitating impact during phonological processing.

The results of the current experiment must be considered in the context of the following limitations. The language skills of the children in this experiment were relatively high. The possibility of superior phonological and semantic skills relative to the mean of the normal population may have affected the results. To generalise the outcome the study needs to be replicated with a different set of children. A further limitation is related to the picture presentation. Although stimuli were presented in random order for each participant, pictures were not controlled for the avoidance of semantically or phonologically related items to appear in direct succession (Valente, Bürki, & Laganaro, 2014). In this way, picture order might have induced a priming effect.

In conclusion, neurophysiological data from 7-year-old children showed no separate main effects of SND and PND at lexical-semantic (P2) or phonological processing (P3). The original hypotheses that predicted amplitude differences between high and low SND at P2, and between high and low PND at P3 respectively, were therefore not confirmed. Instead an interaction between both variables could be revealed for the N2 range (at about 400 ms postpicture onset). Based on past ERP research using picture naming, it was suggested that the interaction effect arises during phonological processing.

The current ERP data indicate that phonological processing of a low PND word is less demanding when it is high in SND than when it is low in SND. The need for greater processing demands was further supported by the behavioural data, showing shorter production latencies for low PND/high SND words compared with low PND/low SND ones. These results indicate processing differences in favour of the hypotheses, with dense neighbourhoods facilitating word production (Dell, 1986). However, ERP data further suggest that high PND/high SND words require more processing effort relative to high PND/low SND words, which does not concur with the hypotheses. Importantly, however, the ERP results were not reflected in the corresponding behavioural data. Words high in PND were produced with the same latency, independent of SND level. Furthermore, high PND words were named significantly faster than low PND ones. These findings point to a decisive and facilitative effect of high PND on processes directly affecting articulation onset, presumably the

retrieval of phonological information. But the findings also suggest that other mechanisms might be required (such as an increase in control processes) in order to direct information retrieval for high PND/high SND words. Importantly, high SND seems not to directly influence the onset of articulation in a high PND condition.

Although the results of the current experiment did not conform entirely with the initial predictions, findings indicate facilitative effects of high PND and high SND on language-related mechanisms that directly influence articulation, and yet it was not one variable alone that determined the ease or difficulty of processing. Rather, it was the interaction of both PND and SND. To reveal the unique effects of each variable one may have to investigate these variables in language systems of younger children.

Findings from the present experiments show that 7-year-olds had a stronger response to PND than the adults did, suggesting a more marked sensitivity to the effects of PND (seen in the ERP data in Experiment 2 and in the behavioural data in Experiment 3). This observation would be in accordance with previous research reporting that PND interacts with age (Gordon & Kurczek, 2014; Newman & German, 2005; Vitevitch & Sommers, 2003). Newman and German (2005), for example, demonstrated that the impact of PND on spoken word production diminished with development. Although they reported poorer naming accuracy for words from dense than from sparse neighbourhoods, this

effect was greater in children (aged 12 to 18 years) than in adults (aged over 20). They even observed that within the children's group the effect of PND steadily declined, since younger children failed more often than older ones to access the appropriate word form for dense words. These results suggest that PND influences naming more strongly in speakers with immature lexical systems (see also Bernstein Ratner et al., 2009). Based on Newman and German's findings, Storkel (2011) argued that "even when a typically developing child knows a word, the underlying lexical and semantic representation may not be as complete and detailed as in the adult lexicon" (p. 425) and stated further that the "completeness of lexical representations is hypothesized to vary by neighbourhood density in children" (p. 425). But Newman and German (2005) further underlined in their study that maturation during childhood influences not only the representations within single processing stages, but also the access pathways between lexical stages (i.e., lemma-to-word form).

Past research additionally indicates that with increasing age and its attendant reading experience, words become more unitary representations in the mental lexicon (Spieler & Balota, 2000), which may not only affect word production but also sensitivity to the effects of linguistic variables, such as PND and SND (Gordon & Kurczek, 2014). The participating children in Experiment 3 were 7 years old, already having reading experience. Examining PND and SND in children younger than 7 years may provide more informative insights into the effects of each variable.

Given the developmental changes mentioned above, younger children may have a more marked sensitivity not only to PND, but also to SND, as their language system may provide conditions for each variable to interfere equally. The same overt picture-naming experiment was therefore conducted with 5-year-old children, most of whom were prereaders. The experiment will be presented in the following section.

6.3 Experiment 4

Experiment 3 with 7-year-old children did not reveal the relative effects of SND and PND on lexical-semantic and phonological processes respectively. Rather, findings indicate that both variables interact during phonological processing, concomitantly influencing processing demands. Yet, as outlined in the previous section, the effect of PND seems to diminish with increasing age, a tendency that could also be observed in the present dissertation studies, with 7-year-olds showing a stronger response to PND than the adults. Approaching children younger than 7 years could give more insights into the effect of PND on phonological processing, since younger children presumably show a more marked sensitivity to PND. Thus, one goal of the present experiment was the further examination of the effect of PND on phonological processing in young children. Therefore 5-year-olds were approached.

The pilot experiments suggested an effect of PND at P3. However, the picture material used in the pilot part may have affected the ERP

signal (see Section 4.3.3), thereby not only obscuring the effect of PND but also the time at which PND comes into play during word production. Experiment 3 showed that N2 was significantly affected by the interaction between PND and SND, with N2 falling in a time period associated with word-form retrieval. This is in accordance with past ERP studies in adults, aligning N2 with phonological processing (e.g., Christoffels et al., 2007; Strijkers et al., 2010). Based on the findings from Experiments 1–3, which point to a facilitative effect of high PND on word production, the hypothesis was:

Five-year-old children produce lower N2 peaks to high PND words than to low PND words.

The corresponding research question was:

Is there a significant difference in mean amplitude of N2 in 5-year-old children between words of high PND and low PND?

A second goal of Experiment 4 was the further investigation of the relative effects of SND during lexical–semantic processing of word production in children. Given the developmental changes outlined in the previous section, younger children may not only have a more marked sensitivity to PND, but also to SND, since their lexical system may provide conditions for SND to interfere separately (e.g., Newman & German, 2005; Spieler & Balota, 2000).

Behavioural results of Experiment 3 showed no main effect of SND but revealed an interaction with PND. In the low PND condition, high SND

were produced significantly faster than low SND, suggesting a facilitative effect of high SND. As past ERP studies of picture naming associated the P2 with lexical–semantic processing (see Section 3.2), the hypothesis was:

Five-year-old children produce lower P2 peaks to high SND words than to low SND words.

The corresponding research question was:

Is there a significant difference in mean amplitude of P2 in five-year-old children between words of high SND and low SND?

The methods were in general similar to those reported in Experiment 3 and will therefore not be repeated in the following sections. Children underwent the same overt picture-naming task with the same stimuli material. Except when specified, all procedures and analyses were identical to those conducted in Experiment 3. Please refer to 6.2.1 for a detailed description of stimuli set, procedure and analyses.

6.3.1 Methods

Ethics approval

This project was approved by the University of Canterbury Human Ethics Committee (reference number HEC 2011/121). Children and their parents gave signed/check marked consent before completing the study.

Participants

Subjects of the study were a subset of children participating in the longitudinal study “Early factors in childhood communication disorders” (a Marsden funded research project). Sixty children aged 5;0 and 5;8 agreed to perform the EEG experiment. In the analysis presented here participants were required to meet the following inclusion criteria: (a) native, monolingual speakers of English; (b) were identified as typically developing; (c) no history of speech, language, or hearing impairment; (d) no serious (chronic) health problems (not taking medication); and (e) normal or corrected to normal vision. Parent report on a questionnaire was used to confirm that children met all of these conditions. Further, only those children who sufficiently attended to the picture stimuli and reached the criterion of $\geq 30\%$ artefact free and correctly answered trials per condition when analysing all word trials of the ERP study were considered. A total of 29 children (16 female, 13 male) met these criteria and were included in the final analyses. The remaining children were aged between 5;0 and 5;7 years with a mean age of 5;3 and a standard deviation of 2 months. All but three participants were right-handed (defined by preference when holding a spoon or pen). An evaluation of the current language performance was based on the receptive and expressive language indexes, ascertained by the *Clinical Evaluation of Language Fundamentals—Preschool*, 2nd ed., Australian and New Zealand Standardised Edition (CELF P-2; Wiig, Secord, & Semel, 2006). All children performed within normal limits for both the receptive and expressive

language skills (receptive language index: mean standard score = 113.28, $SD = 10.96$ and expressive language index: mean standard score = 114.00, $SD = 11.59$). Children received a small gift and a 20\$ voucher for their participation.

Material and Procedures

Stimuli and Procedures (including EEG acquisition and preprocessing) were identical to those in Experiment 3. Children performed the practice trials correctly and could progress onto the experimental trials. The entire experiment lasted about one hour for the 5-year-olds including placement of the electro cap and breaks between the blocks.

Data analysis

Behavioural data

The behavioural analyses were identical to Experiment 3.

Word errors

For both experimental conditions the following types of error responses existed: autocorrection (0.3%), absent reaction (4.9%) and giving an incorrect name (wrong response; 3.9%).

Reaction time

The total of excluded trials shorter than 350 ms was 0.4%.

ERP data

The ERP analyses were identical to those described in Experiment 3 except that time windows were slightly shifted: 0–140 ms (P1 peak), 120–300 ms (N1), 300–380 ms (P2), 380–480 ms (N2) and 480–800 ms (P3). A total of 29 participant reached the criterion of $\geq 30\%$ correctly answered trials per condition after rejection of eye-blinks and artefacts. The statistical approach was the same as outlined in Experiment 3.

6.3.2 Results

Behavioural data

Word errors

Table 6.3 shows the means of two word error types for each condition: wrong response and absent reaction. The two-way ANOVA conducted for wrong responses revealed a main effect for PND $F(1, 28)=14.55, p=.001, \eta^2=.12$. Pictures with low PND evoked more errors than pictures with high PND. No main effect for SND ($F(1, 28)=1.55, p=.223$) or an interaction between PND and SND ($F(1, 28)=1.55, p=.223$) was found.

Table 6.3. Mean and standard deviations of word errors for each experimental condition in 5-year-olds.

	Word Errors	
	Wrong Response	Absent Reaction
	<i>M (SD)</i>	<i>M (SD)</i>
<i>Low PND</i>		
Low SND	2.52 (1.49)	2.41 (2.04)
High SND	1.76 (1.94)	2.52 (2.75)
<i>High PND</i>		
Low SND	1.21 (1.54)	1.86 (2.37)
High SND	1.21 (1.29)	1.34 (1.34)

Note. PND = phonological neighbourhood density; SND = semantic neighbourhood density.

Reaction time

The mean reaction times for each experimental condition are shown in Table 6.4. In the analysis of naming latencies the main effect of PND was significant, $F(1, 28)=5.27$, $p=.029$, $\eta^2=.02$. Pictures with high PND names were produced significantly faster than pictures with low PND names. There was neither a main effect for SND ($F(1, 28)=.51$, $p=.483$) nor an interaction between PND and SND ($F(1, 28)=.43$, $p=.517$).

Table 6.4. Mean and standard deviations of articulation onsets in ms for each experimental condition in 5-year-olds.

	<i>M</i>	<i>SD</i>
<i>Low PND</i>		
Low SND	1127.49	120.58
High SND	1111.44	121.05
<i>High PND</i>		
Low SND	1086.93	139.02
High SND	1086.98	131.77

Note. PND = phonological neighbourhood density; SND = semantic neighbourhood density.

ERP data

Figure 6.5 shows the general structure of the ERP pattern that was characterised by prominent negativities. The effects of PND and SND appeared most pronounced between 300 and 500 ms, which was further confirmed by the statistical analyses.

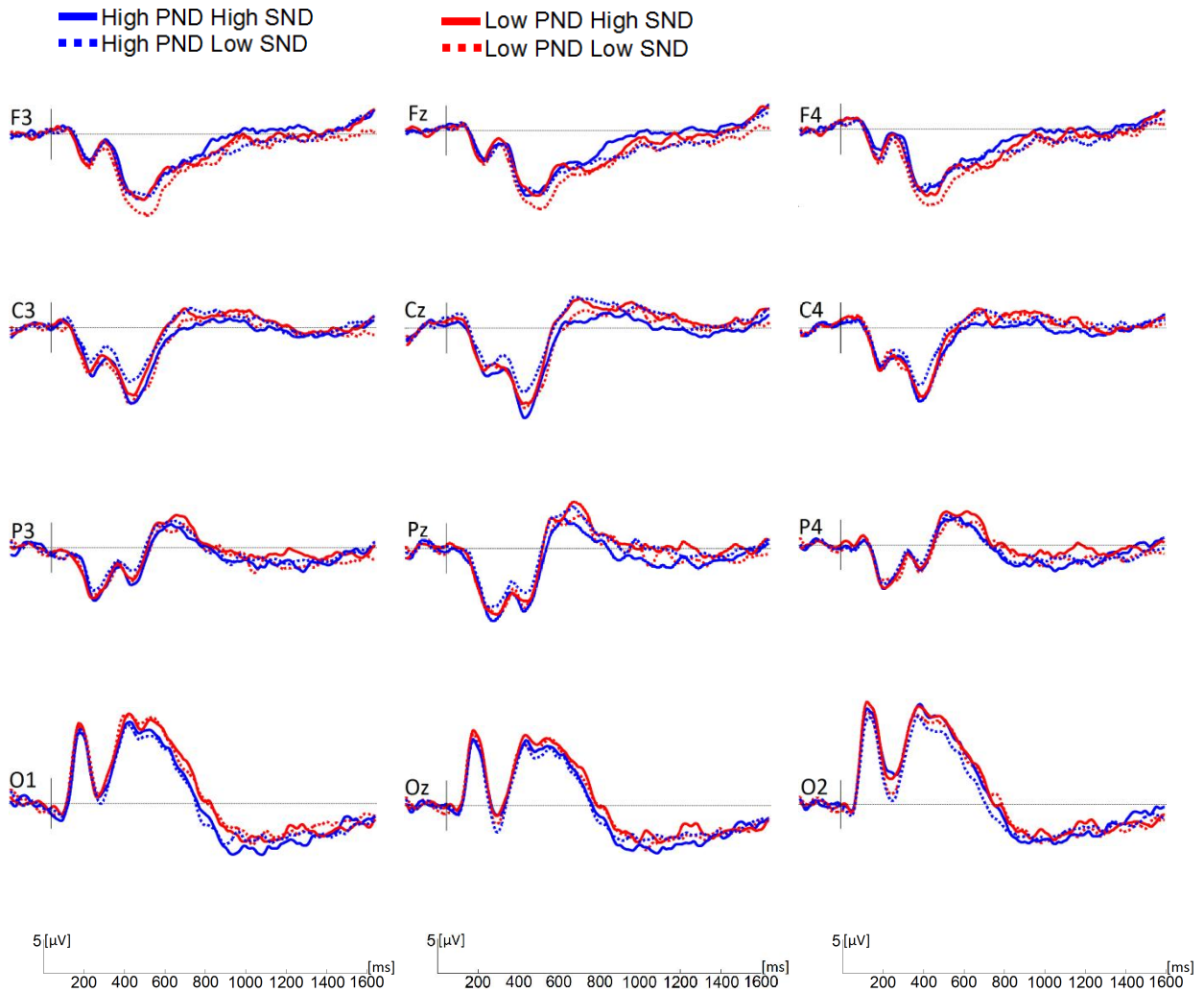


Figure 6.5. Grand averages of ERPs to pictures with different levels of Phonological Neighbourhood Density (PND) and Semantic Neighbourhood Density (SND) in 5-year-olds. To visualise the emergence of the PND and SND effects anterior, central and posterior scalp locations are shown. Positivity is plotted upwards.

Early time windows (P1: 0–140 ms and N1: 120–300 ms):

The only significant main effect found in the early time windows was for Electrode site in the N1 time window, $F(1.35, 37.86)=53.02, p<.001$ (P1: $F(1.56, 43.70)=2.26, p<.128$). No main effect of PND (P1: $F(1, 28)=.03, p=.860$; N1: $F(1, 28)=.02, p=.887$) or SND (P1: $F(1, 28)=.17,$

$p=.687$; N1: $F(1, 28)=.21, p=.653$) was present. None of the ANOVAs showed significant interactions (PND x SND: P1: $F(1, 28)=1.28, p=.268$; N1: $F(1, 28)=1.37, p=.251$; PND x Electrode site: P1: $F(1.44, 40.24)=.11, p=.827$; N1: $F(1.60, 44.83)=.26, p=.726$; SND x Electrode site: P1: $F(1.45, 40.65)=2.05, p=.153$; N1: $F(1.51, 42.29)=3.67, p=.064$; PND x SND x Electrode site: P1: $F(1.56, 43.78)=.76, p=.443$; N1: $F(1.44, 40.33)=.43, p=.587$).

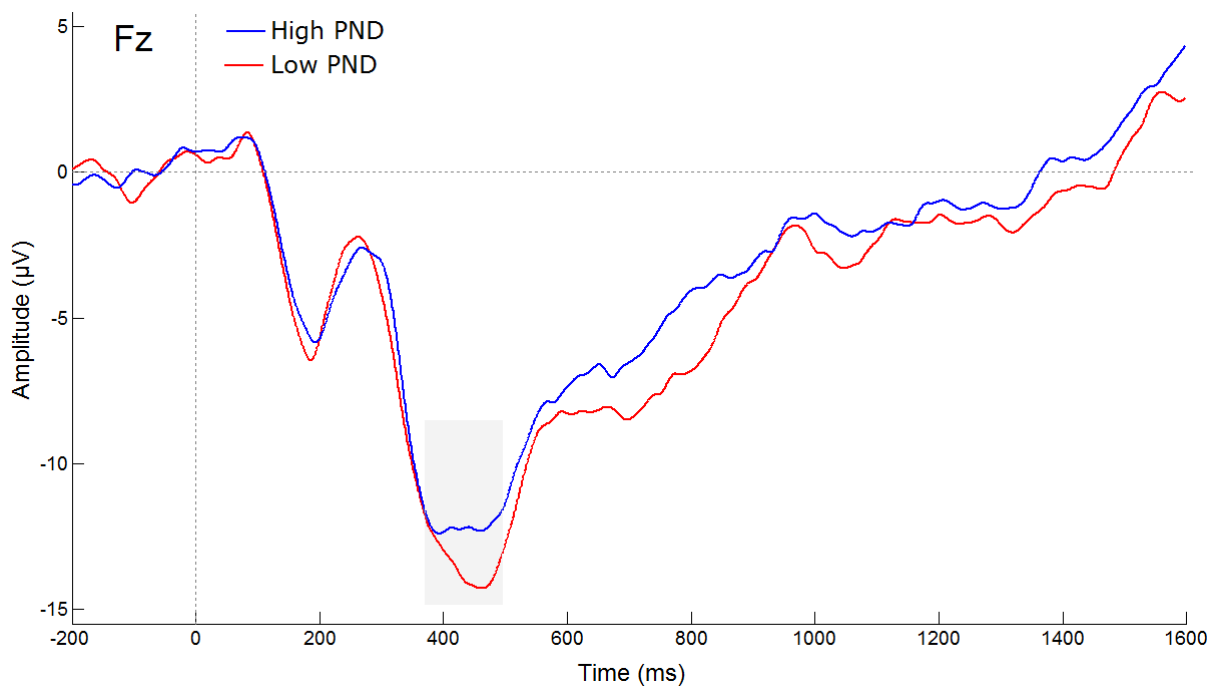


Figure 6.6. High Phonological Neighbourhood Density (PND) ERPs compared with low PND ERPs at Fz showing a significant effect in the N2 time window (380–480 ms).

Later time windows (P2: 300–380 ms, N2: 380–480 ms and P3: 480–800 ms):

ANOVAs showed a significant main effect of PND in the N2 time window, $F(1, 28)=6.36, p=.018, \eta^2=.03$ (P2: $F(1, 28)=.46, p=.504$; P3: $F(1, 28)=.99, p=.329$). Pictures with low PND names showed significantly larger negativities than pictures with high PND names (see Figure 6.6). Main effects for Electrode site were further significant (P2: $F(2, 56)=12.18, p<.001$; N2: $F(2, 56)=7.67, p=.001$; P3: $F(2, 56)=122.77, p<.001$). SND showed no significant main effect (P2: $F(1, 28)=.22, p=.641$; N2: $F(1, 28)=2.35, p=.137$; P3: $F(1, 28)=.10, p=.754$). But a significant interaction between SND and Electrode site was found in the N2 time window, $F(1.53, 42.71)=12.64, p<.001, \eta^2=.03$ (P2: $F(2, 56)=2.06, p=.137$; P3: $F(1.65, 46.19)=.96, p=.376$). Running Tukey's *a priori* *t*-tests revealed that Pz and Cz showed a significant SND effect, with high SND (Pz: $-14.88 \mu\text{V}$; Cz: $-18.26 \mu\text{V}$) evoking more negativity than low SND (Pz: $-12.52 \mu\text{V}$; Cz: $-16.35 \mu\text{V}$), $t(285)=-3.09, p<.005$ (Pz) and $t(285)=-3.82, p<.001$ (Cz), respectively (see Figure 6.7). No such difference was observed at Fz (high SND: $-15.59 \mu\text{V}$ and low SND: $-16.76 \mu\text{V}$), $t(285)=1.89, p>.05$.

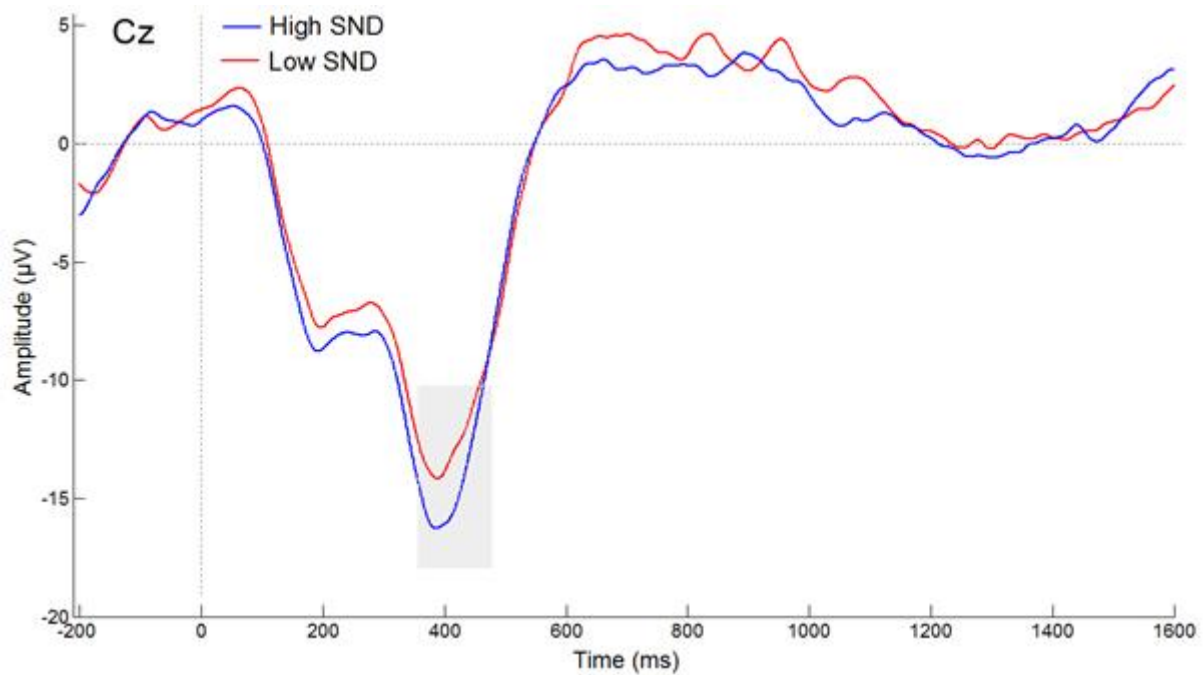


Figure 6.7. High Semantic Neighbourhood Density (SND) ERPs compared with low SND ERPs at Cz showing a significant effect in the N2 time window (380–480 ms).

The interaction between PND and SND was further significant in the N2 time window, $F(1, 28)=8.55$, $p=.007$, $\eta^2=.05$ (P2: $F(1, 28)=2.43$, $p=.130$). The nature of interaction differed depending on electrode sites (see Figure 6.8). At parietal and central sites the effect of SND was larger in the high PND than in the low PND condition. High SND (Pz: $-15.19 \mu\text{V}$; Cz: $-19.02 \mu\text{V}$) evoked significantly more negativity than low SND (Pz: $-10.65 \mu\text{V}$; Cz: $-14.75 \mu\text{V}$), $t(308)=-3.57$, $p<.001$ (Pz) and $t(308)=-3.36$, $p<.001$ (Cz), respectively. No difference existed in the low PND condition (Pz: high SND: $-14.57 \mu\text{V}$ and low SND: $-14.39 \mu\text{V}$, $t(308)=-.14$, $p>.05$; Cz: high SND: $-17.49 \mu\text{V}$ and low SND: $-17.95 \mu\text{V}$, $t(308)=.36$, $p>.05$). At the frontal electrode site an effect of SND was larger in the low PND than

in the high PND condition, with low SND (-18.63 μV) evoking greater negativities than high SND (-15.68 μV), $t(308)=-3.36$, $p<.025$. No such difference was present in the high PND condition (high SND: -15.49 μV and low SND: -14.88 μV), $t(308)=-.48$, $p>.05$. Figure 6.9 further displays the topographic maps for the interaction effect in the N2 time window.

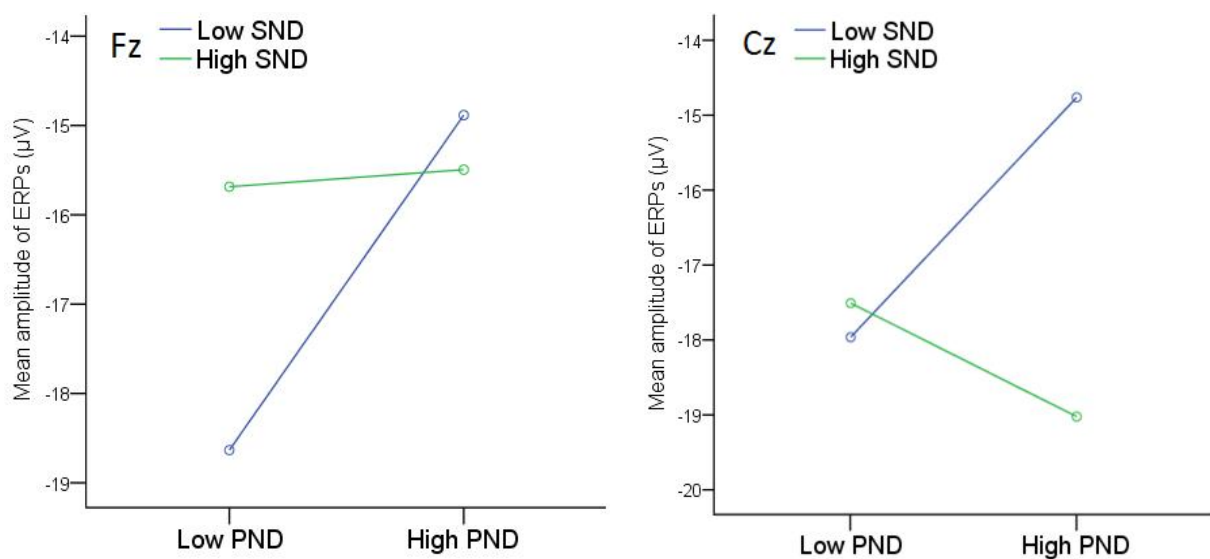


Figure 6.8. The interaction between Phonological Neighbourhood Density (PND) and Semantic Neighbourhood Density (SND) in N2 at electrode sites of Fz and Cz. Amplitude differences between low SND and high SND were larger in the low PND condition at Fz, whereas amplitude differences between low SND and high SND were larger in the high PND condition at Cz.

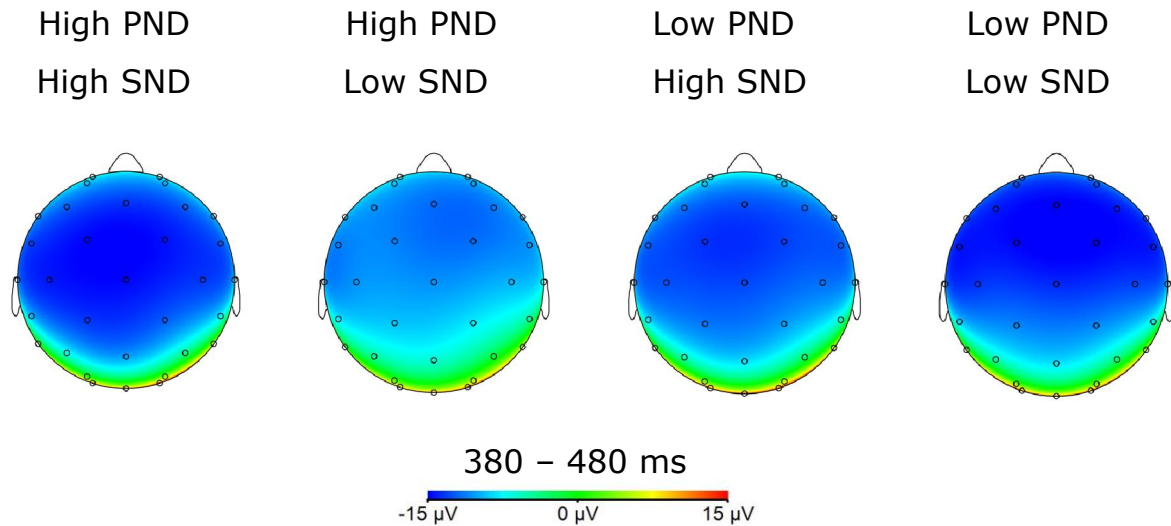


Figure 6.9. Topographic maps for the interaction effect in the N2 time window (380–480 ms).

The interaction between PND and SND was also found to be significant in the P3 time window, though with a smaller effect, $F(1, 28)=4.75$, $p=.038$, $\eta^2=.03$. Amplitudes differed significantly between high SND (7.15 μV) and low SND (5.44 μV) in the low PND condition, $t(519)=2.51$, $p<.01$, but not in the high PND condition (high SND: 6.52 μV and low SND: 7.57 μV), $t(519)=-1.56$, $p>.05$. No other significant interactions were found (PND x Electrode site: P2: $F(2, 56)=.01$, $p=.988$; N2: $F(1.41, 39.56)=.46$, $p=.570$; P3: $F(1.57, 43.83)=2.17$, $p=.136$; PND x SND x Electrode site: P2: $F(2, 56)=.61$, $p=.545$; N2: $F(1.56, 43.78)=.15$, $p=.812$; P3: $F(1.65, 46.14)=3.35$, $p=.053$).

6.3.3 Discussion Experiment 4

In the current experiment ERP and behavioural data were measured while healthy, English-speaking, 5-year-old children overtly named pictures varying in PND and SND. One objective was the further investigation of the relative effects of PND during phonological processing in young children, in order to reveal whether phonologically dense words require less processing demands compared with phonologically sparse words. Based on findings from the prior experiments it was predicted that 5-year-olds produce lower N2 peaks to high PND words than to low PND words. Another aim was the examination of the impact of SND during lexical-semantic processing to gain more insights into its relative effects and associated processing demands. It was predicted that 5-year-old children produce lower P2 peaks to high SND words than to low SND words.

Five-year-old children named pictures with high PND significantly faster than pictures with low PND. These results replicate findings from Experiment 1 and Experiment 3, and are consistent with former behavioural studies that reported faster reaction times for high PND (Baus et al., 2008; Vitevitch, 2002). SND had no main effect on naming latencies. Nevertheless, a facilitative trend induced by high SND in the low PND condition was observed, with low PND/high SND pictures being named faster than low PND/low SND ones. Words high in PND were unaffected by SND, since articulation onsets were identical. Behavioural

data further revealed an effect of PND on naming accuracy. Five-year-olds produced significantly more errors for phonologically sparse words relative to phonologically dense words, a finding that has been reported in earlier studies examining PND effects on naming accuracy in children (e.g., Bernstein Ratner et al., 2009; Freedman, 2013; German & Newman, 2004). Electrophysiological data further supported the effect of PND but also revealed an impact of SND.

The peaks of the ERP waveforms appeared in the following time scale: P1 at around 90 ms, N1 at around 210 ms, P2 at around 300 ms, N2 at around 420 ms, and P3 at around 650 ms. These peaks appeared in a similar time range to those reported in Experiments 2 and 3, although slightly delayed. Similarly to the two former experiments, prominent negative waves could be observed, which has been reported for children in past research (e.g., Greenham & Stelmack, 2001; Laganaro et al., 2015).

The ERP data revealed a main effect of PND in the N2 time window. High PND evoked lower N2 amplitudes than low PND, which is in accordance with the hypothesis, predicting lower N2 peaks to high PND words than to low PND words in 5-year-olds. Turning to SND, data showed that SND did not significantly modulate P2. Although grand average ERP waveforms for Cz and Pz indicated amplitude differences for P2, these modulations were not statistically significant. Instead, a main effect of SND was found at N2, with larger amplitudes to high SND relative to low SND. These findings do not support the original hypothesis, since lower amplitudes were predicted for high SND arising at P2. Unlike the effect of

PND, which was distributed over the three midline electrodes, the effect of SND was only found at the electrode sites of Cz and Pz. Both PND and SND showed similar effect sizes, indicating comparable impacts on underlying processes.

Besides the main effects, an interaction between both variables was also present at N2. Depending on electrode sites the nature of interaction varied. At parietal and central sites the effect of SND was larger in the high PND than in the low PND condition. More specifically, high SND evoked larger amplitudes than low SND for high PND items, while no difference existed between high and low SND for low PND items. However, at the frontal electrode site the effect of SND was larger in the low PND than in the high PND condition, with high SND evoking lower amplitudes than low SND. No differences existed between low and high SND in the high PND condition. An interaction effect between PND and SND was also observed in the P3 range but was less pronounced here. Amplitudes of low and high SND differed significantly only in the low PND but not in the high PND condition. The findings and their theoretical implications will be discussed in the following sections.

Effects of phonological neighbourhood density

In 5-year-old children PND significantly modulated the amplitudes of N2 (at about 420 ms), which has been associated with phonological processing in past ERP studies using picture naming in adults (e.g., Christoffels et al., 2007; Strijkers et al., 2010). The present findings

therefore point to processing differences between high and low PND names during word-form retrieval. Yet it has to be stated that the involvement of phonological operations in the present study appears to be slightly earlier than the estimated chronometry provided by Laganaro et al. (2015; about 480–800 ms postpicture onset).

The current data showed lower N2 amplitudes to high PND relative low PND. These differences suggest lower processing demands (e.g., Dufour et al., 2013; Hunter, 2013; Obleser & Kotz, 2011) for phonologically dense than for phonologically sparse words, thereby underlining a facilitative effect of high PND on word production. These findings can be explained within the framework of interactive spreading activation (Dell, 1986). Due to the increased connectivity between phonological representations in a high PND context, dense words benefit from multiple activations during processing (e.g., Chen & Mirman, 2012), since their phonological forms receive a stronger activation relative to sparse words. The increased activation may occur as a process of distributed neural processing and lower processing effort. The stronger activation during phonological encoding may also accelerate processing, resulting in faster production of high PND than low PND words, as seen in the present behavioural data. Phonologically dense words were named significantly faster than sparse words. The accordance of electrophysiological and behavioural data further indicates that PND affects linguistic processes that directly influence articulation onsets.

Effects of semantic neighbourhood density

SND did not significantly modulate the amplitudes of P2, which has been associated with lexical-semantic processing in past ERP studies using picture naming in adults (e.g., Laganaro et al., 2012; Strijkers et al., 2010). However, the current data of 5-year-olds revealed that SND significantly modulated the amplitudes of N2, with high SND showing larger amplitudes than low SND. Importantly, the effect of SND was restricted to parietal and central electrode sites, while the effect of PND was distributed over the parietal, central and frontal channels. The restricted topography for SND indicates neural source differences (Luck, 2014). The effect of SND may therefore emerge from a different underlying process. The behavioural results further support this assumption. Unlike PND, for SND no association existed between ERP data and behavioural data. High SND names evoked larger amplitudes than low SND ones but the behavioural data was unaffected. These results suggest that the neural processes underlying the N2 effect observed for SND did not directly influence naming latencies. Given these findings, it may be assumed that the effects of SND and PND arise from different stages of processing. Supportive evidence for this assumption comes from past research.

Previous ERP studies that investigated semantic effects during picture naming mainly focussed on semantic-context effects (e.g., Blackford, Holcomb, Grainger, & Kuperberg, 2012; Janssen, Carreiras, & Barber, 2011; Janssen, Hernández-Cabrera, van der Meij, & Barber,

2015). Those studies observed in general a negative-going deflection peaking at approximately 400 ms poststimulus onset and referred to it as a N400-like, negative-going wave, which is commonly interpreted to reflect the processing ease of semantic information (for review see Blackford et al., 2012; Kutas & Federmeier, 2011). Janssen et al. (2011), for instance, collected electrophysiological data while adults overtly named pictures that were presented in blocks in which all items were either from the same semantic category (homogeneous condition) or from different semantic categories (heterogeneous condition). The authors found a main effect of semantic context between 220 and 450 ms postpicture onset, with less negativity for the homogeneous compared with the heterogeneous condition, suggesting that the effect reflects semantic processes. Blackford et al. (2012) used a picture–word interference paradigm in their ERP study and found that pictures preceded by semantically related words evoked a smaller N400-like amplitude than those preceded by unrelated items, with a primarily central distribution. Blackford et al. (2012) explained that “the context word led to some automatic spread of activation to the conceptual and lemma representations of the target picture . . . facilitating access to these representations during naming” (p. 96). Interestingly, even though an attenuated N400 to semantically related words was found, Blackford and colleagues observed longer naming times to pictures preceded by semantically related (versus unrelated) words. While the modulation of the N400 was taken to reflect semantic processing at the interface

between the picture's conceptual features and its lemma, the authors argued that the modulation of the naming times occurred at a later stage of production, that is, after the lemma stage. A similar observation was made in the aforementioned ERP study conducted by Janssen et al. (2011). They reported longer naming latencies for the homogeneous compared with the heterogeneous condition. Taken together, these results suggest the engagement of semantic processes at around 400 ms postpicture onset and further show that the associated ERP modulation is not reflected in the behavioural data. Based on these findings it may be assumed that the present SND effect arises during lexical-semantic processing.

Former research further provides evidence regarding an overlap in time and scalp distribution between semantic and phonological effects during naming (Dell'Acqua et al., 2010; Jescheniak, Schriefers, Garrett, & Friederici, 2002; Jescheniak, Hahne, & Schriefers, 2003). For instance, Dell'Acqua et al. (2010) explored the effects of semantically related and phonologically related words on word production by using a picture-word paradigm. Adult speakers were exposed to to-be-named pictures superimposed on to-be-ignored semantically related or phonologically related words. Results showed semantic and phonological effects arising at around 320 ms poststimulus onset, having partially overlapping sources (semantic effects were confined to temporal and frontal regions; phonological effects overlapped at frontal regions with the semantic effects, but extended to an occipito-temporo-parietal region; Dell'Acqua et

al., 2010). Comparable findings have been made by Jescheniak and colleagues (2002, 2003) using similar picture–word paradigms with adults. They reported that semantic and phonological effects started at around 400 ms after target onset, indicating that the phonological representation of the picture’s name was available at a similar time as the semantic representation. Based on these findings it is suggested that the SND effect arises during lexical–semantic processing, and that the phonological processing may have commenced in parallel with lexical–semantic processing (e.g., Cheng et al., 2010).

The observed modulations of the N2 amplitudes attributed to SND suggest processing differences between high and low SND names during lexical–semantic processing. High SND evoked greater amplitudes than low SND, indicating greater processing demands for words with many semantic neighbours. This finding is not in accordance with the original hypothesis that predicted facilitative processing of high SND words based on the interactive spreading activation account (Dell, 1986). Given that no prior studies exist that have investigated the effect of SND on word production, only an attempt is made to interpret the present findings.

Previous behavioural research that has studied semantic-context effects on word production partially reported interfering effects of semantically related words, by showing longer naming latencies (e.g., Abdel Rahman & Melinger, 2007, 2011; Belke, 2013). The longer naming times were interpreted to be a result of an increased competitive processing during lemma selection, inhibiting lexical–semantic processing.

But EEG studies have repeatedly demonstrated that semantically related contexts evoke lower ERP amplitudes than unrelated contexts (e.g., Blackford et al., 2012; Janssen et al., 2011, 2015). The assumption here is that semantically related contexts facilitate lexical–semantic processing, since targets are coactivated by the related word, thereby ultimately enhancing the targets’ activation (Navarrete et al., 2014).

High SND also provides a condition with a higher activation level of the target (Dell, 1986). However, the data of the current experiment show larger amplitudes to high SND compared with low SND, suggesting inhibited processing. Present behavioural data did not provide further insight, as SND showed no impact on naming accuracy or latency. Thus, it might be that high SND provides a context that requires a more demanding processing during lemma retrieval. Even though high SND may enhance the activation level of the target lemma due to shared concepts (Dell, 1986), high SND might concomitantly increase the recruitment of control processes in order to direct the retrieval toward relevant and nondominant aspects (Noonan, Jefferies, Visser, & Lambon, 2013; Davey et al., 2015; Shao et al., 2014). Given the larger number of coactivation for high SND compared with low SND words, the former condition would require stronger selective inhibition, as represented in an increased N2 amplitude (Shao et al., 2014). Yet this is a very tentative proposal. Additional research is needed to better understand and disentangle the underlying operations.

Interaction between phonological and semantic neighbourhood densities

The current data further showed interaction effects between PND and SND at N2, with a different nature depending on electrode site. At parietal and central channels the effect of SND was larger in the high PND condition. At the frontal site the effect of SND was larger in the low PND condition. Importantly, the direction of the SND effect changed with electrode sites, which could be explained through the involvement of the underlying processes (i.e., lexical-semantic and phonological processing).

At parietal and central sites, high SND showed larger negativities than low SND in the high PND condition, while in the low PND condition high and low SND evoked similar, enlarged magnitudes. These results presumably represent the strong effect of high SND during lexical-semantic processing in both PND conditions, thereby reflecting the need for control mechanisms, as argued above. However, at the frontal electrode site high SND showed significantly lower amplitudes compared with low SND in the low PND condition, suggesting that high SND provides a facilitative effect. In the high PND condition, high SND did not differ from low SND, with both showing attenuated amplitudes, thereby indicating a strong impact of high PND at the frontal site. The ERP data of the frontal site were in accordance with the corresponding behavioural data. Words with high PND showed identical articulation onsets, independent of SND level. Though not significantly different, naming latencies varied in the low PND condition depending on SND level, with

high SND showing shorter reaction times than low SND. The association between behavioural and electrophysiological data suggests that the interaction effect observed at the frontal electrode emerged during a process that directly influences naming latencies (i.e., phonological processing). These findings further indicate that high SND provides a facilitative effect during the assumed phonological processing in a low PND condition. Based on the interactive activation account (Dell, 1986), the enhanced activation at the lexical-semantic level for high SND may increase the activation flow to the corresponding phonological representation, thereby helping with word-form retrieval, and influencing articulatory preparation (Yates et al., 2003). Low SND does not provide such enhanced activation, which may impede phonological processing.

Another interesting observation was the effect of PND at parietal and central electrode sites. More specifically, the effect of low SND varied depending on the PND level. While low SND showed an attenuated amplitude in the high PND condition, its amplitude was larger in the low PND condition, thereby reflecting the main effect of PND, with high PND evoking reduced amplitudes compared with low PND. In the framework of interactive activation (Dell, 1986), semantic representations are less activated for low SND words, which may highlight the PND effect during lexical-semantic processing. The influence of PND at the lemma level can be explained through the bidirectional activation flow between the stages of phonological and lexical-semantic processing (Dell, 1986). That is,

many phonological neighbours enhance not only the activation of the target's phonological representation but also heighten the target lemma based on the interactive activation. Such boost at the lexical-semantic level is rather limited when a word has only few phonological neighbours, which might increase the demand during lemma selection for low PND/low SND words. The need for greater processing demands for low PND words during lemma selection was further supported by the behavioural data. Phonologically sparse words evoked significantly more naming errors than phonologically dense words. A closer inspection of the error type revealed that children predominantly produced semantic errors (e.g., *spoon* for *plate*), indexing the effect of PND during lemma selection, which is in accordance with past research (Laganaro et al., 2013; Middleton & Schwartz, 2011; Sadat et al., 2014).

Similar limitations to those in Experiment 3 have to be acknowledged. The language skills of the 5-year-olds were relatively high, and this may have affected the outcome. Further, the same experimental paradigm was used as in Experiment 3. That is, pictures were not controlled for the avoidance of semantically or phonologically related items to appear in direct succession, which may have induced a priming effect. In addition, it might be that other word-inherent, semantic attributes have contributed to the observed effect of SND, such as the connections among semantic neighbours of a target or the strength of the bidirectional connections between a target word and its semantic

neighbours (Nelson et al., 1998), neither of which have been taken into consideration in the experiment. Further studies are required to investigate potential contributions.

In conclusion, the neurophysiological data from 5-year-old children showed independent effects of PND and SND on underlying processes of word production. In accordance with the original hypothesis, 5-year-olds produced lower N2 peaks to high PND than to low PND words, suggesting reduced processing demands for phonologically dense words during word-form retrieval. Behavioural data further supported the facilitated processing. High PND items were named significantly faster and with more accuracy than low PND ones.

No significant difference in mean amplitude of P2 between words of high SND and low SND could be shown. Instead, SND modulated the N2 amplitude, with high SND evoking larger amplitudes than low SND. Topographical differences for the effects of PND and SND point to different underlying processes, suggesting that N2 can also be associated with lexical-semantic processing in young children. The current findings indicate that semantically dense words require more processing demands during lexical-semantic processing compared with semantically sparse words, which did not conform with the original prediction.

Interaction effects between PND and SND further point to potential impacts of both variables on lexical-semantic and phonological processes. Results suggest a differential effect of high SND during phonological processing, indicating a facilitative influence while processing

phonologically sparse words. The present findings from young children provide new insights into the influential role of PND and SND during word production.

6.4 General discussion of Experiments 3 and 4

Experiments 3 and 4 had two main goals. The first goal was to substantiate the effect of PND during phonological processing of word production in children, to reveal whether phonologically dense words facilitate word-form retrieval. The second goal focussed on the investigation of the impact of SND during lexical–semantic processing of word production in children, to gain more insights into the relative effects of high and low SND and associated processing demands.

Findings from the pilot experiments only provided limited evidence for a facilitative effect of phonologically dense words during phonological processing and did not allow for a clear statement, owing to possible confounding variables, such as the stimulus quality and the low number of trials. Although preliminary, results of the pilot studies indicated the potential impact of coactivated neighbours during information retrieval, which gave rise to the consideration of SND. Investigating the relative effects of SND on lexical–semantic processing allows for a better understanding of how semantic parameters contribute to language processing during word production, which can be relevant for clinical practice.

Past research studying the effects of semantically related words on speech production demonstrated associated processing differences. But findings did not provide specific insights into the impact of a word's semantic neighbourhood, since researchers mostly manipulated the semantic context rather than word-inherent attributes (e.g., Abdel Rahman & Melinger, 2011; Navarrete et al., 2014; Belke et al., 2005). This dissertation made a first attempt to explore the influence of semantic neighbours during word production in children by using the variable of semantic set size (Nelson et al., 1998).

Making use of EEG and ERP, Experiments 3 and 4 were able to detect changes in the strength of neural activation during the production of picture names varying in both phonological and semantic neighbourhood densities. Based on the findings from the pilot experiments, it was expected that 7-year-old children produce lower P3 peaks to high PND words than to low PND words. With respect to SND, the hypothesis was based on the theoretical model of interactive activation (Dell, 1986) and on past EEG research relating the P2 wave of stimulus-locked ERPs to lexical-semantic processing. It was predicted that high SND words would produce lower P2 peaks than low SND words.

Experiment 3 tested the predictions in healthy, English-speaking, 7-year-old children. ERP results showed no unique effects for PND or SND, thereby not confirming the hypotheses. Rather, the ERP data revealed an interaction between both variables at N2 (about 400 ms postpicture

onset) at the frontal electrode site. Depending on PND level, the effect of SND varied. High SND showed lower amplitudes than low SND in the low PND condition, but evoked greater amplitudes than low SND in the high PND condition. The reduced amplitudes to low PND/high SND words relative to low PND/low SND ones indicate processing differences in favour of the hypotheses, with dense neighbourhoods facilitating word processing (Dell, 1986). Yet the greater amplitudes to high PND/high SND words compared with high PND/low SND items are not in line with this assumption.

Based on the estimated time course provided by Laganaro et al. (2015) and former ERP studies aligning N2 with phonological processing, the findings suggest that 7-year-olds experienced greater processing effort during word-form retrieval of low PND/low SND words relative to low PND/high SND ones. To put it another way, high SND seems to facilitate the phonological processing of low PND words. The behavioural data further supported these findings. Low PND/high SND words were named faster than low PND/low SND items. These results suggest that SND had an impact on processes that directly influence the articulation of phonologically sparse words. However, the ERP results for the high PND condition were not reflected in the corresponding behavioural data. Even though SND level modulated the amplitudes, indicating greater processing demands for high PND/high SND than for high PND/low SND words, naming latencies were unaffected, showing almost identical reaction times. These results indicate a decisive effect of high PND on processes

that directly influence articulation onset but also imply that other mechanisms might be required during the phonological processing of high PND/high SND words, in order to direct information retrieval. Behavioural data also revealed a main effect of PND on reaction time, with high PND words being named faster than low PND ones. These results further support the hypothesis that phonologically dense words are facilitative of word production.

As no independent effects of PND and SND on underlying processes of word production could be shown in Experiment 3, Experiment 4 approached 5-year-old children. The consideration of a younger age group was based on findings from past research suggesting a stronger impact of PND with decreasing age and a separate interference of each variable owing to a less mature language system (Gordon & Kurczek, 2014; Newman & German, 2005; Spieler & Balota, 2000; Vitevitch & Sommers, 2003). Based on the results of Experiment 3, the hypothesis was that 5-year-olds produce lower N2 peaks to high PND than to low PND words. For SND it was expected that high SND would produce lower P2 peaks than low SND words.

ERP data of 5-year-olds showed independent effects of PND and SND at N2, with similar effect sizes. High PND evoked lower N2 amplitudes than low PND, confirming the original hypothesis. These results point to lower processing demands for phonologically dense words during word-form retrieval compared with phonologically sparse words.

Behavioural data further support this assumption, showing faster naming latencies for high than for low PND items.

SND did not evoke significant amplitude differences between high and low SND words at P2. However, significant amplitude differences between words of high SND and low SND were found at N2. High SND words showed larger amplitudes than low SND, which was not predicted. Unlike PND, ERP data of SND were not in accordance with the behavioural findings, since naming latency and accuracy were unaffected by SND, suggesting that the effect of SND emerged at a different underlying process than the effect of PND. This was further supported by topographical differences between the SND effect and the PND effect. Based on findings from previous ERP research, the SND effect at N2 was related to lexical–semantic processing. That is, results indicate that 5-year-olds produced high SND words with more effort during lexical–semantic processing than low SND words.

Findings further indicated interactions between PND and SND during both processing stages (i.e., lexical–semantic and phonological processing). Interestingly, the effect of high SND differed, depending on the processing stage. While high SND evoked larger amplitudes in both high and low PND conditions during lexical–semantic processing, amplitudes to high SND were attenuated in both low and high PND conditions during phonological processing. That is, high SND seems to increase processing demands during lemma retrieval, but seems to decrease the efforts during phonological processing. The facilitative

tendency of high SND was also present in the corresponding behavioural data, with low PND/high SND words showing shorter latencies than low PND/low SND ones, though was not statistically significant.

Taken together, the results from 5-year-old children suggest that phonologically dense words are facilitative of word production, since processing demands during word-form retrieval are reduced and articulation onsets accelerated, relative to phonologically sparse words. Findings also provide first insights into the effect of SND during lexical-semantic processing and further underline the potential impact of SND on phonological processing, as was indicated in Experiment 3.

Findings from Experiment 3 and Experiment 4 indicate that children experienced lower processing demands during the retrieval of the phonological form of high PND relative to low PND names, resulting in faster articulation onsets for high PND words. Findings further indicate that high SND can be facilitative in interaction with low PND during phonological processing. Seven- and 5-year-olds showed consistently lower amplitudes to high SND in a low PND condition during phonological processing, pointing to reduced processing demands when SND is high.

Results also indicate developmental changes regarding the effects of PND and SND on underlying processes. Unlike 7-year-olds, 5-year-olds revealed independent impacts of each variable, indicating that PND and SND may influence the information retrieval more strongly in immature lexical systems, as suggested in past research literature (e.g., Newman &

German, 2005). In comparison with 7-year-olds, 5-year-olds are less linguistically proficient speakers. The observation that naming accuracy was affected in 5- but not in 7-year-old children may point to the limited automatisisation of lexical access (e.g., Seiger-Gardner & Schwartz, 2008). An immature strength of connections with respect to lexical information presumably provides conditions for each variable to interfere equally. The increase in language experience and concomitant neurodevelopment allows for a faster interneuronal communication (O'Muircheartaigh et al., 2014) and automatisisation of production processes, presumably incorporating simultaneously SND and PND effects.

Given the different sample sizes, which may have influenced the outcome, this is only a suggestive interpretation. The experiments were not conducted to explicitly compare both age groups but rather to reveal the relative effects of PND and SND on the underlying processes of word production in young children. Still, the observed findings suggest that there is a developmental change of PND and SND on word production. Further research will need to address this issue to provide more insights and to bolster current findings.

The most relevant findings of the conducted experiments are:

- The substantiation that phonologically dense words are facilitative during phonological processing of word production in children, implying that phonologically sparse words require greater processing demands.

- Semantically dense words increase processing demands during lexical–semantic processing in young children, which does not affect the behavioural response (i.e., naming latency and accuracy).
- SND interacts with PND during phonological processing, thereby providing facilitation through high SND in low PND conditions.

These findings enrich our understanding of how phonological and semantic relatedness among words can influence the ease of processing during speech production in children.

Chapter 7

Conclusion

7.1 Short synopsis

This dissertation addressed the effects of phonological and semantic neighbourhood densities on word production in children. Of particular interest were the changes of processing demands during the production of words varying in phonological and semantic neighbourhood densities. Chapter 4 and Chapter 6 provided neurophysiological and behavioural data that converge on the proposal that the production of phonologically dense words requires less processing effort during phonological processing relative to phonologically sparse words. Chapter 6 provided neurophysiological and behavioural data that converge on the proposal that semantically dense words require greater processing demands than semantically sparse words during lexical-semantic processing and that semantic neighbourhood density affects the ease of processing of phonologically dense and sparse words during word-form retrieval.

This dissertation expands previous research and contributes to a better understanding of how word-inherent properties can influence the word production process in children. In comparison to past research, the present work focussed not only on the behavioural performance but also investigated corresponding electrophysiological data, thereby directly examining the whole process of word production. This thesis therefore

extends earlier results by revealing processing difficulties in real-time and by mapping processing differences to associated underlying cognitive operations (Indefrey, 2011; Laganaro et al., 2015). In that way, current findings provide more informative data about the potential impacts of semantic neighbourhood density and phonological neighbourhood density on lexical-semantic and phonological processing.

By providing a better understanding about the effect of phonological neighbourhood density on phonological processing, the results presented are able to complement previous findings from language development research (Stokes, 2014). Furthermore, the present work takes an empirical step toward the impact of a word's semantic neighbourhood density on speech production in children, thereby expanding past research that focussed on semantic aspects mainly via semantic context effects (e.g., Brooks et al., 2014; Jerger et al., 2002). The current findings therefore contribute to a better understanding of how language production is shaped by word-inherent semantic properties. In addition, the empirical data contribute to the scarce electrophysiological literature regarding language production in children, thereby forming a baseline of the neurophysiological correlates of word production for children with and without communication disorders.

The present electrophysiological data recorded from healthy, English-speaking adults and children revealed larger ERP amplitudes to phonologically sparse relative to phonologically dense words during time periods associated with phonological processing in picture naming. These

results point to processing differences between phonologically dense and phonologically sparse words during word-form retrieval, with dense neighbourhoods requiring lower processing demands compared with sparse neighbourhoods. By providing neurophysiological evidence of processing demands for high and low phonological neighbourhood densities, the present results expand beyond behavioural research (e.g., Arnold et al., 2005; Baus et al., 2008; Vitevitch & Stamer, 2006).

The fourth dissertation study, with young children, showed concordance between electrophysiological and behavioural data in regard to the effect of phonological neighbourhood density, with phonologically dense words showing facilitated word-form retrieval and accelerated articulation onsets relative to phonologically sparse words. These findings support the assumption that difficulties during phonological encoding may be a cause of late-talking children predominantly using phonologically dense words (Stokes, 2014).

The fourth dissertation study further revealed an effect of semantic neighbourhood density on lexical-semantic processing in young children. The electrophysiological data showed larger ERP amplitudes to semantically dense words relative to semantically sparse words, suggesting greater processing demands for the former compared with the latter word type. Interestingly, behavioural data were unaffected by the preceding processing differences, since articulation onsets did not differ between semantically dense and sparse words. By providing neurophysiological data for the effect of semantic neighbourhood density

in children, the current results expand previous research that mostly focussed on adults and the manipulation of semantic contexts rather than word-inherent semantic attributes (e.g., Abdel Rahman & Melinger, 2007; Belke, 2013; Costa et al., 2005; Navarrete et al., 2014).

The third and the fourth dissertation studies additionally revealed interactions between phonological and semantic neighbourhood densities during phonological processing, with semantic density reducing the processing demands particularly for phonologically sparse words. This finding suggests that semantic neighbourhood density modulates the processing costs during phonological processing, which could be taken into account when targeting output processes in clinical populations (discussed in more detail in the following section).

7.2 Implications of this work

Apart from theoretical contributions, results from this thesis also have clinical implications, although interpretation must be cautious, given that the samples were relatively small. Nevertheless, current findings underline the consideration of phonological parameters in the context of early language intervention when targeting expressive vocabulary. Results suggest that PND affects phonological processing during speech production, with phonologically sparse words requiring more demand than phonologically dense words.

Chapter 1 of the thesis pointed out the theoretical assumption made by Stokes (2014) that late-talking children have difficulties with activating the correct word form for phonologically sparse words. The present findings support this suggestion, by providing a potential link between observed behavioural results and neurological underpinnings. Of course, current data are based on healthy, typically developing children. We ultimately need to go further and investigate underlying processes of speech production in late talkers, to determine whether phonological encoding deficits exist by revealing corresponding deviances. Still, present findings point to the potential impact of low PND on phonological processing and also hint that language proficiency may modulate the influence of PND (by presumably stressing the output process more strongly in weaker lexical systems, with further research necessary to explore this hypothesis).

Focussing intervention on the phonological properties of words and practising their production may be beneficial for late-talking children. The knowledge that high PND evokes better performance could be used to guide the choice of words and eventually promote the production of phonologically sparse words. More specifically, therapists could firstly focus on practising words that reside in phonologically dense neighbourhoods, thereby considering the corresponding neighbours. In this way vocabulary size would not only increase, but robust phonological representations would also be established, as repeated stimulation of

connections strengthens interneuronal communications (O'Muircheartaigh et al., 2014). Based on this achievement, the therapist could then gradually introduce words from sparser phonological neighbourhoods (Stokes, 2014). Given the additional finding that semantic neighbourhood density interacts with phonological neighbourhood density during phonological processing, it may be helpful to consider semantic neighbours too. Stokes (2014) showed that phonologically sparse words are in the receptive lexicon of late talkers, indicating that semantic representations or properties are available. Current results showed greater processing costs for low PND/low SND words compared with low PND/high SND ones. Assuming that late talkers experience deficits during phonological encoding, words low in SND may further impede processing when targeting phonologically sparse words. Instead, incorporating high SND in a low PND condition might facilitate processing. Future research is warranted to determine how integrating PND and SND into the treatment may assist late-talking children and affect the growth of their expressive lexicons.

7.3 Directions for future research

While the present findings increase the knowledge of how language processing in children is affected by a word's phonological and semantic neighbourhood density, future work is required to fully understand the novel data, and to explore the deeper implications of these. It is important

to replicate the present observations and to further investigate the effects of neighbourhood densities on underlying processes.

The replication of the PND and SND experiment with adults can give more insights regarding the location of the underlying neural generators, since an increased channel set could be used, allowing the realisation of source analysis techniques. Associated findings can help to substantiate the underlying processes affected by PND and SND assumed here. The replication of the present findings in even younger children will provide more evidence about phonological and semantic effects on word production in children, and will also verify the ERP responses in picture naming in typically developing children, which can be used as a benchmark to compare them with the responses of children with language impairment. Accordingly, another future direction is the consideration of clinical populations. Investigations of this type will gain more insights into the impacts of semantic and phonological parameters on output processes in children with language disorders and will help to better understand why speech is impaired. If we can demonstrate empirically that children with language impairment produce brain responses deviating from those of typically developing children, we can address underlying deficits more specifically. Despite the difficulties in this attempt, research along these lines will lead to a better understanding of atypical language processing: a precondition to ensure that early language intervention is most effectively targeted in children who struggle to talk.

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Appendix A: List of stimuli used in Experiment 1 and Experiment 2

High Phonological Neighbourhood	Low Phonological Neighbourhood
Ball	Ant
Bat	Bath
Beach	Bib
Boat	Dog
Bus	Farm
Cake	Fish
Chair	Fly
Coat	Goose
Duck	Kiss
Fork	Knife
Hat	Leg
Lamb	Nose
Light	Nurse
Moon	Shirt
Nail	Soup
Pen	Star
Roof	Tooth
Sheep	Tree
Sock	Watch
Sun	Zip

Appendix B: Index of Phonetic Complexity (IPC)

Calculating the Index of Phonetic Complexity for a word is based on eight parameters:

- 1. Consonants by Place Class:** One point for *each* dorsal.
- 2. Consonants by Manner Class:** One point for *each* fricative, affricate, and liquid.
- 3. Vowels by Class:** One point for *each* rhotic.
- 4. Word Shape:** One point if the word ends in a consonant.
- 5. Word Length in Syllables:** One point for words with three or more syllables.
- 6. Singleton Consonants by Place Variegation:** One point if a word has singleton consonants that vary in place.
- 7. Contiguous Consonants:** One point for each consonant cluster.
- 8. Cluster by Type:** One point if there is place variation between the consonants comprising a cluster.

The points that were scored for each parameter of the IPC are added and represent a word's complexity value.

Note. From "Acquisition of phonetic complexity in children 12-36 months of age," by K. J. Jakielski, R. L. Matyas and E. N. Doyle, 2006, Poster presented at the Annual Meeting of the American Speech-Language-Hearing Association, Miami, FL. Copyright 2006 by K. J. Jakielski. Adapted with permission.

Appendix C: Copyright permission Index of Phonetic Complexity

I Kathy J. Jakielski agree to grant you a non-exclusive licence for an indefinite period to include the above materials, for which I am the copyright owner, in the print and digital copies of your thesis.

Electronic Signature: Kathy J. Jakielski

Date: February 23, 2016

Appendix D: Phonetic Complexity Scoring for word stimuli used in Experiment 1 and Experiment 2

Word Stimulus	Consonant by Place	Consonant by Manner	Vowels	Word Shape	Word Length in Syllables	Singleton Consonants by Place Variegation	Contiguous Consonants	Cluster Type
Ant	0	0	0	1	0	0	1	0
Ball	0	1	0	1	0	1	0	0
Bat	0	0	0	1	0	1	0	0
Bath	0	1	0	1	0	1	0	0
Beach	0	1	0	1	0	1	0	0
Bib	0	0	0	1	0	0	0	0
Boat	0	0	0	1	0	1	0	0
Bus	0	1	0	1	0	1	0	0
Cake	2	0	0	1	0	0	0	0
Chair	0	1	0	0	0	0	0	0
Coat	1	0	0	1	0	1	0	0
Dog	1	0	0	1	0	1	0	0
Duck	1	0	0	1	0	1	0	0
Farm	0	1	0	1	0	0	0	0
Fish	0	2	0	1	0	1	0	0
Fly	0	2	0	0	0	0	1	1
Fork	1	1	0	1	0	1	0	0
Goose	1	1	0	1	0	1	0	0
Hat	0	0	0	1	0	1	0	0
Kiss	1	1	0	1	0	1	0	0
Knife	0	1	0	1	0	1	0	0
Lamb	0	1	0	1	0	1	0	0
Leg	1	1	0	1	0	1	0	0
Light	0	1	0	1	0	0	0	0

Appendix D (continued): Phonetic Complexity Scoring for word stimuli used in Experiment 1 and Experiment 2

Word Stimulus	Consonant by Place	Consonant by Manner	Vowels	Word Shape	Word Length in Syllables	Singleton Consonants by Place Variegation	Contiguous Consonants	Cluster Type
Moon	0	0	0	1	0	1	0	0
Nail	0	1	0	1	0	0	0	0
Nose	0	1	0	1	0	0	0	0
Nurse	0	1	0	1	0	0	0	0
Pen	0	0	0	1	0	1	0	0
Roof	0	2	0	1	0	1	0	0
Sheep	0	1	0	1	0	1	0	0
Shirt	0	1	0	1	0	0	0	0
Sock	1	1	0	1	0	1	0	0
Soup	0	1	0	1	0	1	0	0
Star	0	1	0	0	0	0	1	0
Sun	0	1	0	1	0	0	0	0
Tooth	0	1	0	1	0	0	0	0
Tree	0	1	0	0	0	0	1	0
Watch	0	2	0	1	0	1	0	0
Zip	0	1	0	1	0	1	0	0

Appendix E: List of stimuli used in Experiment 3 and Experiment 4

Neighbourhood Density			
High Phonological		Low Phonological	
High Semantic	Low Semantic	High Semantic	Low Semantic
Bag	Bed	Cheese	Arm
Ball	Bell	Dice	Bath
Bird	Cap	Drum	Belt
Boat	Cat	Fence	Brush
Bone	Cow	Fish	Cloud
Bowl	Fork	Ghost	Dog
Bus	Hat	Hand	Foot
Cake	Kite	Shirt	King
Duck	Leaf	Snake	Leg
Heart	Moon	Star	Mouse
Sheep	Nail	Swing	Nest
Sword	Pear	Train	Plate
Whale	Pen	Tree	Spoon
Witch	Sock	Truck	Zip

Appendix F: Phonetic Complexity Scoring for word stimuli used in Experiment 3 and Experiment 4

Word Stimulus	Consonant by Place	Consonant by Manner	Vowels	Word Shape	Word Length in Syllables	Singleton Consonants by Place Variegation	Contiguous Consonants	Cluster Type
Arm	0	0	0	1	0	0	0	0
Bag	1	0	0	1	0	1	0	0
Ball	0	1	0	1	0	1	0	0
Bath	0	1	0	1	0	1	0	0
Bed	0	0	0	1	0	1	0	0
Bell	0	1	0	1	0	1	0	0
Belt	0	1	0	1	0	0	1	0
Bird	0	0	0	1	0	1	0	0
Boat	0	0	0	1	0	1	0	0
Bone	0	0	0	1	0	1	0	0
Bowl	0	1	0	1	0	1	0	0
Brush	0	2	0	1	0	0	1	1
Bus	0	1	0	1	0	1	0	0
Cake	2	0	0	1	0	0	0	0
Cap	1	0	0	1	0	1	0	0
Cat	1	0	0	1	0	1	0	0
Cheese	0	2	0	1	0	1	0	0
Cloud	1	1	0	1	0	0	1	1
Cow	1	0	0	0	0	0	0	0
Dice	0	0	0	1	0	1	0	0
Dog	1	0	0	1	0	1	0	0
Duck	1	0	0	1	0	1	0	0
Drum	0	1	0	1	0	0	1	0
Fence	0	2	0	1	0	0	1	0
Fish	0	2	0	1	0	1	0	0

**Appendix F (continued): Phonetic Complexity Scoring for word stimuli
used in Experiment 3 and Experiment 4**

Word Stimulus	Consonant by Place	Consonant by Manner	Vowels	Word Shape	Word Length in Syllables	Singleton Consonants by Place Variegation	Contiguous Consonants	Cluster Type
Foot	0	1	0	1	0	1	0	0
Fork	1	1	0	1	0	1	0	0
Ghost	1	1	0	1	0	0	1	0
Hand	0	1	0	1	0	0	1	0
Hat	0	0	0	1	0	1	0	0
Heart	0	0	0	1	0	1	0	0
King	2	0	0	1	0	0	0	0
Kite	1	0	0	1	0	1	0	0
Leaf	0	2	0	1	0	1	0	0
Leg	1	1	0	1	0	1	0	0
Moon	0	0	0	1	0	1	0	0
Mouse	0	1	0	1	0	1	0	0
Nail	0	1	0	1	0	0	0	0
Nest	0	1	0	1	0	0	1	0
Pear	0	0	0	0	0	0	0	0
Pen	0	0	0	1	0	1	0	0
Plate	0	1	0	1	0	0	1	1
Sheep	0	1	0	1	0	1	0	0
Shirt	0	1	0	1	0	0	0	0
Snake	1	1	0	1	0	0	1	0
Sock	1	1	0	1	0	1	0	0
Spoon	0	1	0	1	0	0	1	1
Star	0	1	0	0	0	0	1	0
Swing	1	1	0	1	0	0	1	1

Appendix F (continued): Phonetic Complexity Scoring for word stimuli used in Experiment 3 and Experiment 4

Word Stimulus	Consonant by Place	Consonant by Manner	Vowels	Word Shape	Word Length in Syllables	Singleton Consonants by Place Variegation	Contiguous Consonants	Cluster Type
Sword	0	1	0	1	0	0	1	1
Train	0	1	0	1	0	0	1	1
Tree	0	1	0	0	0	0	1	0
Truck	1	1	0	1	0	0	1	0
Whale	0	1	0	1	0	1	0	0
Witch	0	1	0	1	0	1	0	0
Zip	0	1	0	1	0	1	0	0

Appendix G: Letter for ethical approval Experiment 1



HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen

Email: human-ethics@canterbury.ac.nz

Ref: HEC 2013/93

17 July 2013

Professor Stephanie Stokes & Dr Bill Gavin
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Stephanie

The Human Ethics Committee advises that your research proposal "Neurophysiological correlates of phonological neighbourhood density effects on language processing" has been considered and approved.

Please note that this approval is subject to the following:

- Please ensure the information sheet and consent form are two separate forms – this is to enable participants to keep a copy of the information sheet for their records.

Best wishes for your project.

Yours sincerely

A handwritten signature in black ink, appearing to read 'L. MacDonald'.

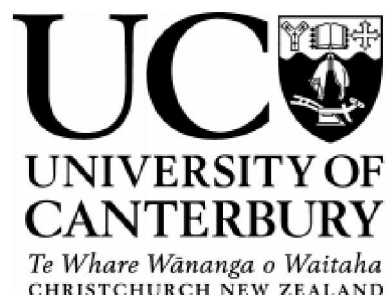
Lindsey MacDonald
Chair

University of Canterbury Human Ethics Committee

Appendix H: Consent form for participants Experiment 1

Consent Form - Adults

Neurophysiological correlates of phonological neighbourhood density effects on language processing



Professor Stephanie Stokes
Department of Communication Disorders
University of Canterbury
Private Bag 4800
Christchurch 8140

DATE

I, _____ have read and understood the information sheet for the brain waves study and hereby give my consent for my participation. This means that I will come to the child language centre at the University of Canterbury for about 1 hour. I understand that I can ask for the study to stop at any time, without penalty. I agree to the publication of the results with the understanding that confidentiality will be preserved. Stephanie Stokes has answered any questions that I have had. I can get the project results by contacting Dr. Stokes. I note that the project has been reviewed and approved by the University of Canterbury Human Ethics Committee.

Please print your name _____

Signed _____ Date _____

THANK YOU

**Appendix I: Letter for ethical approval Experiment 2 and
Experiment 3**



HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffin
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2013/134

29 November 2013

Doreen Hansmann
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Doreen

The Human Ethics Committee advises that your research proposal “Influences of phonological neighbourhood density of word production in seven-year-old children: an ERP study” has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 4 November 2013.

Best wishes for your project.

Yours sincerely

A handwritten signature in black ink, appearing to read 'L. MacDonald'.

Lindsey MacDonald
Chair
University of Canterbury Human Ethics Committee

**Appendix I (continued): Letter for ethical approval Experiment 2
and Experiment 3**

**Re: Extension to Hansmann_2013_HEC 134 - Amendment approved - Lynda
for file please.**

Lindsey MacDonald

Sent: Monday, 15 September 2014 11:10 a.m.

To: Stephanie Stokes

Cc: Lynda Griffioen; Doreen Hansmann

Dear Stephanie

Approved. Though I hope the title on the information and consent form is more understandable to the average person!

thanks, and congratulations to Doreen on moving from phase 1 to phase 2 of the research.

Kind regards, Lindsey

Lindsey MacDonald PhD
Lecturer (Political Science)
Room 605, Locke Bldg
Department of Political Science
School of Social and Political Sciences
University of Canterbury
Private Bag 4800
Christchurch 8140
Chair, University of Canterbury Human Ethics Committee

Appendix J: Consent form for participants Experiment 2 and Experiment 3



BRAINWAVE PATTERNS DURING PICTURE NAMING



Parent Consent Form

DATE _____

I have read and understood the information sheet for the brainwaves study and hereby give my consent for my son/daughter _____ (your child's name here), to join the project. This means that I will come with my child to the Child Language Centre (7 Creyke Road) at the University of Canterbury for about 90 minutes.

I understand that my child's brainwaves are recorded by use of a special cap during picture naming tasks. The cap is put on by two research assistants.

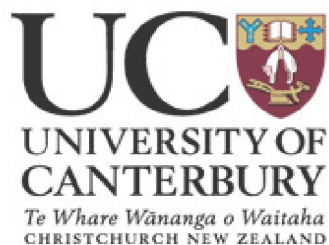
I understand that my child will only participate if he/she gives verbal consent to indicate that he/she wants to do the study. He/she does not have to take part, and s/he can stop at any time. I understand that my child's name is not noted and no-one will know which results are my child's. The electronic data will be stored on a secure website and may be used for other research and academic purposes. I understand that my child will receive a \$10 Westfield voucher and a small gift.

Doreen Hansmann and Stephanie Stokes have answered any questions that I, or my child, have had. I note that the project has been reviewed and approved by the University of Canterbury Human Ethics Committee. I know that this is a project of the University of Canterbury, NZ and is funded by this University. I know that the results of the study will be released in the usual way by public lectures, news releases, and written articles. I understand that I can contact Doreen Hansmann and/or Stephanie Stokes to receive a copy of the findings of the study.

Please print your name _____

Signed _____

Appendix J (continued): Consent form for participants
Experiment 2 and Experiment 3



**BRAINWAVE PATTERNS DURING
 PICTURE NAMING**



Child Consent Form

I _____ agree to do these things - (TICK YES OR
 NO BELOW)

	<p>Put on the cap and the face sensors?</p> <p>YES:</p> <p>NO:</p>
	<p>Name some pictures?</p> <p>YES:</p> <p>NO:</p>
	<p>Point to the picture (e.g. sleeping)?</p> <p>YES:</p> <p>NO:</p>

Appendix K: Letter for ethical approval Experiment 4



HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2011/121

14 January 2015

Professor Thomas Klee
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Professor Klee

Thank you for your request for an amendment to your research proposal "Early factors in childhood communication disorders" as outlined in your letter dated 9 January 2015.

I am pleased to advise that this request has been considered and approved by the Human Ethics Committee.

Yours sincerely

A handwritten signature in black ink, appearing to read 'L. MacDonald'.

Dr Lindsey MacDonald
Chair
University of Canterbury Human Ethics Committee

Appendix L: Consent form for participants Experiment 4



Consent Form

Learning to Talk research study (Age 5)

You may cross out any of the following statements you do not agree with:

1. I have read and understood the information given to me about the research project named above. I have had a chance to ask questions and have had them answered. I understand that my child's and my participation in this project are voluntary and that we are free to withdraw at any time without giving a reason. I understand that the sessions will be video and audio recorded. I understand that the information you collect from us will remain confidential and will be securely stored at the university. I understand that any presentations or publications resulting from this project will not refer to us by name. I understand that this project has been reviewed and approved by the University of Canterbury Human Ethics Committee. On this basis, my child (named below) and I agree to participate in this research project.
2. I agree to also let the researchers use the audio-video recording for teaching purposes at the university with the understanding that you will not refer to us by name.
3. I agree to also let the researchers use the audio-video recording at research conferences with the understanding that you will not refer to us by name.

MY CHILD'S NAME (please print):

MY NAME (please print):

My Signature:

Date:

I may be contacted by:

- ☐ Email
- ☐ Cell phone
- ☐ Landline
- ☐ Post

☐ I would like you to send me a brief summary of your findings when the study is complete.

Main Researcher: Professor Thomas Klee, Email: ChildLanguageCentre@canterbury.ac.nz,
Phone: 03 364 2987 ext. 8501

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. www.canterbury.ac.nz